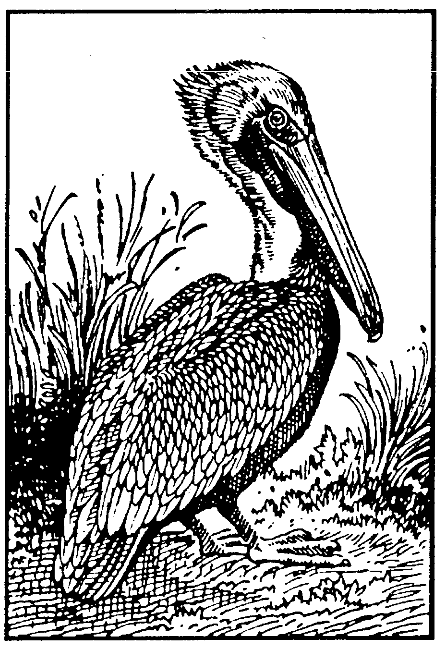
US Army Corps of Engineers
Waterways Experiment Station

Wetlands Research Program Technical Report WRP-RE-17

Proceedings of the National Workshop on Geotextile Tube Applications

by Jack E. Davis, Mary C. Landin



April 1997 – Final Report

The following two letters used as part of the number designating technical reports of research published under the Wetlands Research Program identify the area under which the report was prepared:

	Task		Task
CP	Critical Processes	RE	Restoration & Establishment
DE	Delineation & Evaluation	SM	Stewardship & Management

Wetlands Research Program

Technical Report WRP-RE-17
April 1997

Proceedings of the National Workshop on Geotextile Tube Applications

by Jack E. Davis, Mary C. Landin

U.S. Army Corps of Engineers
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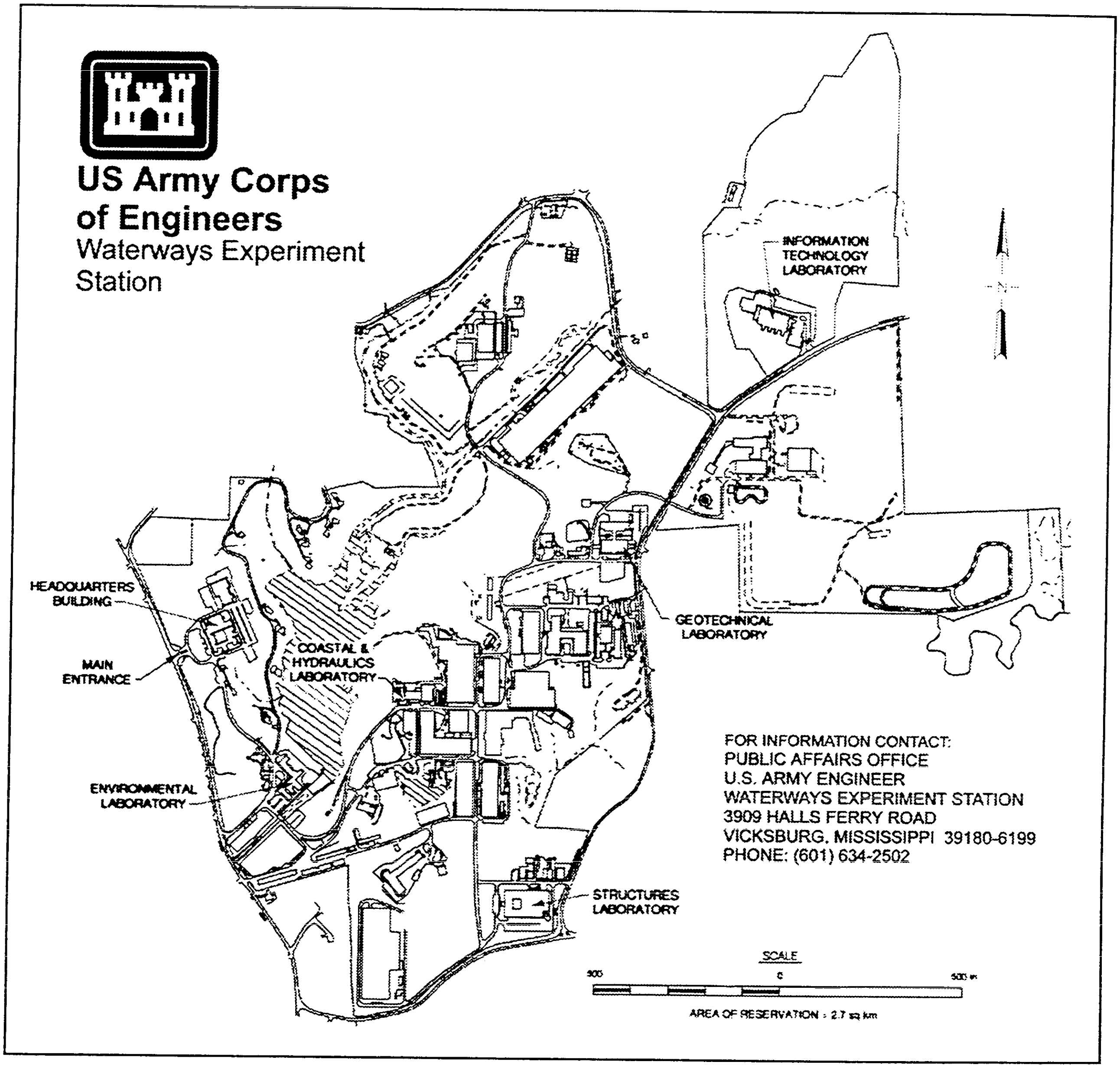
Final report

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000



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Wetlands Restoration

Proceedings of the National Workshop on Geotextile Tube Applications (TR WRP-RE-17)

ISSUE:

The U.S. Army Corps of Engineers has used increasingly in recent years geotextile tubes filled with sand for the retention and erosion protection of dredged material in low wave energy, low-tidal range regimes. However, little guidance is available to help field personnel design and deploy geotextile tubes.

RESEARCH:

A workshop was conducted to document the state-of-knowledge of geotextile tube design and deployment. The workshop focused on existing capabilities to design geotextile tube structures and lessons learned from field deployments.

SUMMARY:

Notes from the workshop presentations and discussions are summarized within. Some conclusions are made regarding best practices, and subjects requiring further study are identified.

AVAILABILITY OF REPORT:

The report is available on Interlibrary Loan Service from the U.S. Army Engineer Waterways Experiment Station (WES) Library; 3909 Halls Ferry Road, Vicksburg, MS 39180-6199; telephone (601) 634-2355.

To purchase a copy, call the National Technical Information Service (NTIS) at (703) 487-4650. For help in identifying a title for sale, call (703) 487-4780. NTIS report numbers may also be requested from the WES librarians.

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Contents

Preface

The work described in this report was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE), as part of the Characterization and Restoration of Wetlands Research Program (CRWRP) Work Unit "Technical Standards and Guidance for Wetlands Restoration and Creation." Mr. Samuel Collinson (CECW-OR) was the CRWRP Technical Monitor for the work.

Mr. Dave Mathis (CERD-C) was the CRWRP Coordinator at the Directorate of Research and Development, HQUSACE, and Dr. Russell F. Theriot, U.S. Army Engineer Waterways Experiment Station (WES), was the CRWRP Manager. Dr. Mary C. Landin, WES, was the Principal Investigator of the Work Unit.

This report was prepared by Mr. Jack E. Davis, Coastal and Hydraulics Laboratory (CHL), WES, and Dr. Landin. Authors who contributed sections to this proceedings are Dr. Jack Fowler, Geotech, Inc., Vicksburg, MS; Mr. Edward Trainer, Nicolon Corporation, Norcross, GA; Dr. Lee Harris, Florida Institute of Technology, Melbourne, FL; and Messrs. Neil McLellan, George Turk, Robert N. Blama, John B. Palmerton, Wendell Mears, Charles Thompson, and Charles Mesa and Dr. Landin, all of the U.S. Army Corps of Engineers.

This report was prepared under the general supervision of Dr. Morris Mauney, Chief, Wetlands Branch, and Dr. Conrad J. Kirby, Chief, Ecological Research Division (ERD), Environmental Laboratory (EL), WES. Dr. Edwin A. Theriot was the Assistant Director, EL, and Dr. John W. Keeley was Director, EL. The report was reviewed by Dr. William Brostoff, ERD, and Dr. Yu T. Chou, CHL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

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Agenda

15 August 1995, Tuesday

0800 - 0820	Opening -- **Mike Palermo**, Workshop Moderator, Welcome Objectives for the Workshop -- **Jack Davis**
0820 - 0845	Topic I: Geotextile Tube Deployment and Filling Technique -- **Jack Fowler**
0845 - 0900	Discussion
0900 - 0930	Galveston District Case Studies -- **Neil McLellan**
0930 - 0945	Discussion
0945 - 1000	BREAK
1000 - 1030	Topic II: Hydrodynamic Engineering Design -- **George Turk**
1030 - 1045	Discussion
1045 - 1115	Baltimore District Case Studies -- **Bob Blama**
1115 - 1130	Discussion
1130 - 1230	LUNCH (District cafeteria)
1230 - 1300	Topic III: Geotechnical Engineering Design -- **John Palmerton**
1300 - 1315	Discussion
1315 - 1345	Mobile District Case Studies -- **Wendell Mears**
1345 - 1400	Discussion
1400 - 1430	Topic IV: Geotextile Characteristics -- **Ed Trainer**
1430 - 1445	Discussion
1445 - 1500	BREAK
1500 - 1530	Florida Case Studies -- **Lee Harris**
1530 - 1545	Discussion
1545 - 1615	Detroit District Case Studies -- **Charles Thompson**
1615 - 1630	Discussion
1630 - 1645	BREAK
1645 - 1715	Los Angeles Case Studies -- **Chuck Mesa**
1715 - 1730	Discussion

16 August 1995, Wednesday

0800 - 0830	Topic V: Risk and Contingencies -- **Mary Landin**
0830 - 0845	Discussion
0845 - 1030	Wrap-up Discussions
1030 - 1045	BREAK
1045 - 1115	Field Trip Briefings

1115 - 1700 Depart for Port of Houston Authority Demonstration Marsh geotextile tube location. We will stop and eat lunch en route to site and return to the Holiday Inn in Galveston when this portion of the field trip is concluded.

17 August 1995, Thursday

Field Trip to Geotextile Tube Projects Near Seadrift/Port Lavaca, TX

0800 Depart Holiday Inn on the Beach
1130 Arrive Seadrift/Port Lavaca, Hotel check-in, Eat lunch
1300 Depart Seadrift in Galveston District launches
1400 Arrive at Ayers Island and False Live Oak Island projects
1700 Depart for Victoria Barge Canal project
1800 Arrive Victoria Barge Canal project
1900 Depart for Seadrift
1915 Arrive at Seadrift and return to hotel

18 August 1995, Friday

Travel day; workshop concluded.

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
inches	2.54	centimeters
ounces (mass)	28.34952	grams
pounds (mass)	0.4535924	kilograms

Introduction

The U.S. Army Corps of Engineers has been using geotextile tubes increasingly in projects to provide temporary or permanent breakwaters, especially when coupled with dredged material with a goal of wetland restoration or other natural resource beneficial uses. The first applications of geotextile fabrics in wetlands and habitat development was in the early 1970s in Galveston Bay, Texas, and in the late 1970s in Core Sound, North Carolina. Although the habitats being built were different, the construction techniques were similar. Large nylon bags (12 by 4 by 3 ft)[1] were filled in place hydraulically with sandy dredged material to form stacked breakwaters. At the time, it was assumed that in both situations, the bags would eventually fail, leaving behind a well-established habitat that could maintain itself. Both of these projects will be discussed in greater detail later in this proceedings.

By the mid-1980s, the Corps was testing and using 100-ft-long, 3-ft-diam Longard tubes made of low tensile strength geotextiles. These were all used in underwater situations to improve water quality, to provide surge protection, and to protect seagrass and other aquatic habitats. Their design and construction was awkward, and the tubes were very hard to fill. They also were not very stable under the tested conditions.

In the early 1990s, the Corps began testing and using custom-made geotextile tubes made of 400 to 1,000 test strength fabric as breakwaters. These were tested as both water-filled, temporary tubes to be removed after the project was completed and sediment-filled, permanent tubes that would never be removed. Tube lengths have ranged from 100 ft to 2,000 ft long and circumferences have ranged from 20-45 ft. Enough problems occurred and questions arose on various projects with placing, filling, and working with tubes that District project managers requested technical information and assistance.

After responding to a number of individual requests for help over a 3-year period, the U.S. Army Engineer Waterways Experiment Station (WES) conducted a workshop for individuals working on tube projects. Basic information on selected topics was presented, with a major emphasis on discussion and problem-solving. Invited participants were selected from Corps Headquarters, Districts and laboratories, Port Authorities who had tube projects, contractors who have been placing and filling tubes, consultants who have worked on tube projects, and the manufacturers of geotextile tubes. The list of participants and workshop agenda reflect the comprehensive effort made to get all of the major entities involved. The workshop was sponsored by the Wetlands Research Program, the Dredging Research Program, and the Dredging Operations Technical Support Program, all at WES, and was

[1] A table of factors for converting non-SI units of measurement to SI units is presented on page xiii.

hosted by the U.S. Army Engineer District, Galveston. It was held in the Holiday Inn on the Beach conference room in Galveston, TX. A field trip to the Port of Houston wetland demonstration project was hosted by the Port of Houston Authority, Gahagan and Bryant Associates, Inc., and Turner Collie Braden, Inc., all of Houston, TX. Field trips to Aransas National Wildlife Refuge, Victoria Barge Canal, and other geotextile tube projects in the Texas Gulf Intracoastal Waterway were hosted by the Galveston District.

The objective of the workshop was to bring together all major groups and individuals using geotextile tubes for wetland and habitat restoration and protection and to present and discuss deployment and filling techniques, hydrodynamic engineering design, geotechnical engineering design, geotextile fabric characteristics, and risks and contingencies related to biota, natural resources, and nontechnical aspects. The objective of these proceedings is to document and transmit the pertinent information gained during the workshop and to provide summaries to all participants.

Topic I: Geotextile Tube Deployment and Filling Technique

by
Jack Fowler[1] *and Neil McLellan*[2]

Dr. Fowler mentioned the current Construction Productivity Advancement Research Program where geotextile containers are being developed and demonstrated for confining fine-grained and contaminated sediments. The project is a partnership between the U.S. Army Engineer Waterways Experiment Station and the Nicolon Corporation. The Corps of Engineers and partner are contributing about $400,000 to the project, either through funding or in-kind services. The U.S. Army Engineer District, Los Angeles, is another participant in the project. The study is discussed in more detail in the presentation by Mr. Chuck Mesa below.

Geotextile tube projects are generally simple to construct. The tube is filled directly with dredged material from the outflow of a hydraulic dredge. In these applications, the geotextile tube is created by sewing two sheets of fabric together. The sheets are laid over one another and their edges sewn together. The length of the tube is discretionary. Circular holes about 12 to 18 in. in diameter are cut into the top piece of fabric along the center line of the tube. Sleeves about 3 ft long are sewn around the holes. The holes serve as access points for filling the tube. Generally, for very fine-grained materials (silts and clays), filling sleeves can be spaced 500 ft apart. For sands, the filling sleeves should be about 50 to 75 ft apart.

During construction, the dredge discharge pipe is fitted into the filling sleeve and strapped tight. As dredged material is pumped into the tube, the solids fall out of suspension, and the excess water flows out other ports and permeates the tube fabric (if permeable fabric is used).

Galliard Island, Alabama. Dr. Fowler discussed an early geotextile tube project at Galliard Island, Alabama, which was conducted in 1991. In this project, the tubes were used to raise the height of containment dikes around a 1,400-acre confined disposal facility in Mobile Bay. The questions addressed by the project included whether fine-grain materials could be used as a construction material and whether geotextile tubes could be used as structures, particularly to increase the cross sections of retaining dikes (e.g., increase the height of an existing dike) or cross-dikes. The tubes were constructed out of the water. Because of their availability, muds were used to fill the tubes, rather than sands. The dredged material was pumped directly into the geotextile tubes. The tubes were cradled between small wind rows of dirt, which prevented the tubes from rolling. The pipe coming off the dredge was a 30-in.-diam pipe with an operating pressure of 18 psi. An 8-in.-diam pipe was taped into the 30-in. pipe and run to the geotextile tube. The pressure in the 8-in. pipe was measured at 4 psi. The pipe pressure has to be reduced for filling the tubes because excessive pressure can cause the tube to rupture, especially if the fabric is already stressed or the fabric has been damaged (e.g., abraded during transport). An erosion

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[1] Geotech, Inc., Vicksburg, MS.

[2] U.S. Army Engineer District, Galveston; Galveston, TX.

control blanket was installed beneath the tube that extended to either side of the tube. Dr. Fowler stressed that the use of an erosion control (scour) blanket is a necessity. The specific gravity of the material being pumped was nearly the same as its in situ value of 1.3. A 500-ft-long tube filled with 1,000 cu yd of material took 90 min to fill. However, the fill was the consistency of a fluid that dewatered and consolidated over time resulting in a 75-percent loss in tube height. After 1 year, the material inside the tube was dry and cracking, similar to the material placed within the containment facility.

Dr. Fowler pointed out that some phragmites (*Phragmites australis*) grew through the fabric. He suggested that vegetation growing through holes in the fabric may ultimately damage the integrity of the fabric. He also noted that since the site's construction, brown pelicans (*Pelecanus occidentalis*) have used the area in large numbers. Their appearance at the site was not due to the presence of the geotextile tubes, but it was worth noting that at least the tubes did not detract from their using the area.

Avalon Beach, New Jersey. Dr. Fowler referred to polypropylene geotextile tubes installed at Avalon Beach, New Jersey. The tubes were placed in shallow water parallel to the waterline between rock groins. Sandy fill was placed behind them to augment the beach. The project is intended to reduce flooding. A similar project is located on Rikers Island in New York.

Smith Island, Maryland. Geotextile tubes made of polypropylene fabric were installed in 1994 in shallow water adjacent to Smith Island. The tubes were used as containment dikes for the placement of sandy dredged material. The installation was funded by the U.S. Army Engineer District, Baltimore. The contractors had difficulty filling the tubes to heights greater than 4 ft. The tubes had a circumference of 30 ft. The Baltimore District personnel suspect that the tubes may have been too large and the dredge used to fill them too small.

Atlantic City, NJ. Geotextile tubes were placed in 1995 in front of the boardwalk along Atlantic City's beach as part of a municipal shore protection project. Apparently, sand is forced beneath the boardwalk during storms, which damages the structure. A trench was excavated along the existing dune, and an impermeable barrier (such as plastic) was placed in the trench. The tube was placed in the trench on top of the impermeable fabric. An induction pump was used to dredge sand off the beach and fill the tubes. The impermeable underliner captured water permeating out of the tube and directed it to an outlet to prevent erosion around the tubes. Figure 1 shows the tube under construction. The tube was then covered over with sand and vegetated, giving the site the appearance of a natural dune. The design was unobtrusive. In the event of a storm, the tube would become exposed and act as shore protection. Hence, the tube is hidden protection, only becoming evident when erosion begins. The project weathered a recent storm in which the tubes were exposed and the boardwalk was protected.

Destin, FL. Geotextile tubes were installed in 1991 at Destin, FL, as groins very near the East Pass inlet. The tube groins are each 200 ft in length. Each tube was placed on a scour blanket and slit open on its crest to allow sandbags to be placed inside. The geotextile tubes have not deteriorated, but have been covered partially by sand due to coastal processes.

Lake Peoria, Illinois. A containment dike made of geotextile tubes was designed to be placed in the shape of a donut, then filled with material dredged from the lake. This reservoir has silted in to an average depth of 3 ft and has severe water quality problems. The dike's purpose was to break up waves in the shallow lake and provide protection to the headwaters area to allow submersed aquatic vegetation, fisheries, and wildlife use to recover. The project was designed for the U.S. Army Engineer District, Rock Island, as part of the Upper

Figure 1. Construction of the geotextile tube in front of the Atlantic City, NJ, boardwalk

Mississippi River Environmental Management Program. It has not been constructed at this time.

Sills for Blocking Saltwater Intrusion. Dr. Fowler mentioned the conceptual use of geotextile tubes to act as sills across the thalweg of a river channel. The sills could prevent the intrusion of saltwater wedges in upper reaches of a river.

Barren Island, Maryland. Geotextile tubes were placed in 1995 to act as retaining dikes for sandy dredged material. The site was chosen to protect the island from continued erosion, provide for new marsh development, and prevent the dredged material from dispersing. At this site, polyester fabric tubes 37 ft in circumference were used. The polyester is a light sand color. It is also 1,000-lb/in. strength fabric, whereas the polypropylene is 400 lb/in.

Port of Oakland, California. Dr. Fowler also mentioned that at the Port of Oakland, fine-grained contaminated sediments were bucket dredged into a hopper barge. A Toyo submersible hydraulic pump was then lowered into the barge and the material pumped into geotextile tubes. In a test, a geotextile tube was filled on the surface of Pier 10. Dr. Fowler noted that the tube tended to roll during filling because the pier had a very mild slope (designed to allow drainage of precipitation from its surface). He said that 4,000 cu yd of contaminated material were placed this year in geotextile containers by the New York District. The Jacksonville District was conducting bioassays on material from the Miami River to see if the contaminated material would be confined by geotextile containers. The river has potentially one million cubic yards of material. It has not been dredged since the 1930s.

The following are comments from discussions after Dr. Fowler's presentation.

Final Tube Height. Final tube height is important when the tube is used for erosion control structure. To get height, the tube must be pumped up as much as possible during filling so that as sediment is introduced, it takes on that pumped-up shape. However, pressures have to be watched to be sure that the tube will not rupture. It was recommended that the permeability of the tube be reduced if necessary to help maintain the pressure inside the tube (keep it inflated). The permeability could be reduced somewhat by lining part of the interior of the tube with Visqueen. The flow velocity in the tube must be great enough to transport sand down the length of the tube. It helps to have workers walk along the length of the tube as it is filling to help level the sand inside the tube. Sand is required for maintaining a given elevation after filling is complete. Fine material and muds will take a long time to settle and consolidate. As they do so, the tube will gradually lose its initial height. Dr. Fowler suggested that the ratio of final tube height to initial height be 1:1 for sand and 1:4 for muds. (Recall that the Galliard Island project had a 1:4 ratio.)

Some participants suggested that a rule-of-thumb for determining the final tube height is one-sixth to one-fourth of the circumference of the tube. For example, a tube with a 30-ft circumference could be expected to reach a final height of 5 to 7.5 ft. The subsequent presentations suggested that final height is dictated by the filling process and equipment, the circumference of the tube, the fabric permeability, filling-sleeve spacing, and the material used to fill the tube. It appeared that tubes of smaller circumference were able to reach higher height-to-circumference ratios than larger circumference tubes. However, the observations are based on only a few cases, and the construction techniques and environmental conditions were quite different.

Stacked Tubes. The problem of stacking tubes was brought up many times in the workshop. Recommendations from this discussion were that stacked tubes need to be tied together somehow because the friction angle between top and bottom tubes is low, with a value around 18°. The friction angle for tubes on sand is about 25°. Hence, the tendency of a tube to slide off another tube is greater than the tendency for a tube to slide on seabed sediments. Tubes have been attached by sewing them together.

Filling Time With Sand. Dr. Fowler said it takes about 6 hr to fill a 500-ft-long tube with sand. Other presenters noted that on their projects, it sometimes took as much as 9 hr to fill 250 ft of tube.

Fabric Selection. Dr. Fowler said that nonwoven fabrics can be used on the inside of a tube to lower permeability and woven fabric on the outside for strength. If the tubes are intended to contain contaminated materials, the tube can be tested by placing in situ material in a small tube and analyzing the water that escapes for contaminant concentrations.

For scour blankets, Nicolon 750 was used. The edge of the fabric is folded back 2 ft and sewn, forming a small tube that can be filled with sand. These small tubes help anchor the scour blanket.

Filling-Sleeve Spacing. The spacing between ports along a tube can be specified by the buyer. Some workshop participants found that using more filling ports lead to less variation in the height of the tube along its length. However, some participants reportedly filled 250-ft-long tubes using just one filling port located near one end of the tube.

Filling Techniques. Contractors that installed geotextile tubes for the Galveston District said that they found success by first placing approximately 6 in. of sand through each filling sleeve to hold the tube in place. (Note that the polypropylene tubes that they were using float.) After the tube was suitably anchored, they began filling through each sleeve in turn until the tube reached its maximum height.

Modeling Tube Shape. A computer program was developed as part of CPAR for predicting tube geometries. Mr. John Palmerton from the U.S. Army Engineer Waterways

Experiment Station (WES) is the point of contact for the CPAR model reference.

Case Studies Presentation. Mr. McLellan stated that the Galveston District dredges between 35 and 40 million cubic yards of material per year from the navigation channels within its District. He noted that the first use of geotextile tubes was in 1972 at Bolivar Peninsula on the east side of Galveston Inlet. The tubes though deteriorated are still in place today, and the marsh planted in the lee of the tubes is thriving.

West Bay Project. The District carried out its first geotextile tube design in 1991 for a project along the Gulf Intracoastal Waterway (GIWW) in West Bay north of Galveston Island. The project created an island 5,000 ft long and 225 ft wide parallel to and on the seaward side of the GIWW. The island provided protection from waves for navigation in the GIWW, and it provided shore protection for the north (landward) side of the GIWW, which had been experiencing erosion. In fact, the erosion was threatening a breach into a brackish and ecologically productive body of water called Halls Lake.

The island was created by forming a ring dike and filling the interior with dredged material to an intertidal marsh elevation. The fine-grained dredged material was taken from the GIWW during the District's scheduled channel maintenance work. Marsh vegetation was then planted. Most of the retaining dikes were earthen and protected from erosion by a variety of techniques. However, 1,000 ft of dike was replaced by a low-crested geotextile tube. The low tube acted as the overflow region for the dredging operations.

The tube constructed by Kingfisher Marine was made of polypropylene fabric from Nicolon Corporation and was 22.5 ft in circumference. The tube was filled to a rough height of 3.5 ft with sand from a local source. The contractors had difficulty placing the tube on a straight alignment. The crest elevation of the tube varied along its length as well. But the variations in alignment and elevation did not affect the effectiveness of the tube. In fact, the tube's effectiveness may have been enhanced. The variations along the tube allowed variations in wave energy transmitted passed the tube, which resulted in a more random marsh edge behind the tube.

The geotextile tube was underlaid by a fabric blanket to protect against scour. The scour blanket was made from a Nicolon weave 70-20. The blanket was about 24 ft wide and was made by sewing two 12-ft-wide sections of fabric together. The edges of the blanket were held down by an 18-in.-diam tube created by folding the edge of the fabric over on itself and sewing it. This is done by the manufacturer.

The project was constructed in the summer of 1992. The contractors deployed only a portion at a time (about 300 ft) of the continuous 1,000-ft-long tube off the back of a barge. The portion of the tube in the water was then filled with sandy material taken from a nearby location. The contractor used a dredge pipe less than 10 in. in diameter to fill the tube, which kept internal tube pressures down. As the sand was introduced to the tube, workers walked the length of the tube to help even out the level of the fill inside the tube. The contractors were given in their contract specifications for the desired tube length, height, fabric characteristics, and scour blanket characteristics, but it was left to them to determine the best technique for constructing the tube.

The tube was placed to a crest elevation of +1.0 MLW. Mr. McLellan noted that the astronomical tide fluctuations are less than 1 ft, but that meteorological conditions can force water into the bay to levels 1 ft or more above the astronomical tide high tide. The low tube crest elevation allows water to flow over the marsh during high-water periods, providing sufficient tidal exchange with the developing marsh. After 2½ years, the geotextile tube structure has provided very good protection for low marsh in its lee. In fact, the tube has remained in place and has subsided very little, while the earthen dikes to either side of the tube have migrated under the wave forces. Mr. McLellan stated that the best marsh areas are in the lee of the geotextile tube. He indicated that another similar project is being considered near this project and would likely be constructed during the next channel-maintenance period.

Aransas National Wildlife Refuge Project. Another wetland restoration project was constructed at the Aransas National Wildlife Refuge in an effort to increase the amount of available habitat for the endangered whooping crane that winters each year at the refuge. Based on characteristics of wetlands in the refuge, the whooping crane (*grus americana*) population would seem to prefer habitat with 40-percent uplands, 40-percent low-lying marshes, and 20-percent open water.

The wetland restoration and dredged material placement site was on the south side of an existing but eroding unconfined dredged material island that has not been used since before 1975 (when unconfined placement was banned). A 3,000-ft geotextile tube containment dike was constructed to retain dredged material placed at the site to an intertidal elevation. The tubes extended bayward from the island about 400 ft and ran parallel to the island for about 2,200 ft. Figure 2 provides an aerial view of the project. Most of the tubes were 22.5 ft in circumference. A few, however, were 15 ft in circumference. The contractor was limited to using a 10-in. dredge pipe to limit internal tube pressure during filling. The tube was made from Nicolon F570 and had filling sleeves sewn into the tube every 100 ft.

The dredged material in the tubes was a mixture of sand and fine-grained sediments. During construction, two failures occurred as seams in the tube ruptured. However, Mr. McLellan noted that even though failures occurred, the tube filled well to either side of the failure. They tried two methods for repairing the ruptured seams. For the first rupture, the seam was sewn back together using a hand-held sewing machine. The tube was refilled. For the second rupture, a smaller tube was placed over the area and filled. After the tubes were filled, sandbags were used to plug joints between tubes that did not abut one another well. Mr. McLellan said that the sandbags washed out and deteriorated quickly after the marsh construction was completed. However, the small gaps left open between the tubes enhanced tidal flushing characteristics for the site and allowed ingress and egress for aquatic organisms. While some case study speakers and workshop participants noted that tubes sometimes roll during the filling process, Mr. McLellan noted that he has not experienced that problem on the projects with which he has been involved.

Mr. McLellan noted an associated problem with the project design where the geotextile tube simply terminated on the shoreline of the existing island. No steps were taken to prevent erosion from occurring on the island where the tube terminated. Increased erosion occurred because waves striking the tube obliquely traveled along the tube until they struck the shoreline. The intensity of the waves striking the shoreline was increased, resulting in accelerated erosion.

After 2 years, the tubes are still in good condition; the fabric scour blanket and anchor tubes are covered with sediment; and the marsh that was planted in the lee of the structures is developing quite well.

Port O'Connor Project. At Port O'Conner, a small beach fill project was constructed. Project participants had some concern that local coastal processes might transport sand from the beach fill and cover salt marshes and seagrass beds. Rather than spend an excess of money to determine whether that might occur, a geotextile tube acting as a groin was placed between the beach fill and the marshes and seagrasses. If transport occurred in either direction, it would be blocked by the geotextile tube. Hence, a relatively inexpensive deployment of a

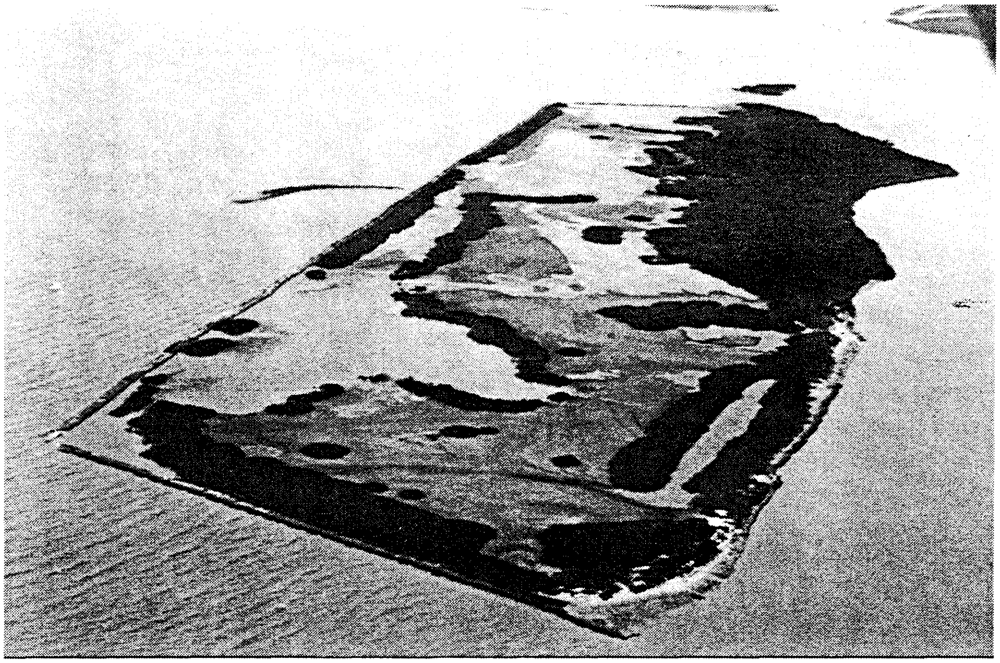

Figure 2. Aerial view of the geotextile-tube dredged material containment structure near Aransas National Wildlife Refuge

temporary geotextile tube groin allowed the District and concerned parties time to consider the situation and observe the processes that occur without risking damage to the marshes or seagrasses.

The groin was constructed in March of 1993 from a single 400-ft-long tube perpendicular to shore in 1 to 2 ft of water. The tube was deployed off a roll mounted on the end of a dredging barge. An 8-in.-diam dredge pipe was used to fill the tube. The tube is approximately 4 ft high. During the first 18 months, the tube deflated near a cut several feet long in the top of the tube, apparently the result of vandalism. (The tube is easily accessed by the public.) However, the height of the tube to either side of the cut remains at its initial height. Other less damaging forms of vandalism were evident, particularly holes made in the tube to hold fishing rods. To the surprise of most people, the accumulation of sediments occurred on the side opposite to that expected, i.e., sediment appeared to be moving from the marsh area toward the beachfill. Mr. McLellan also noted that barnacles and oysters had colonized on the sides of the tubes, sea grasses were growing nearby, and many hermit crabs could be found along the crest of the tube.

Victoria Barge Channel Project. Mr. McLellan mentioned another project that was constructed in the summer of 1994 to contain dredged material, create wetland habitat, and prevent the continued erosion of an island that borders the barge canal. The dredged material at the site was retained by earthen dikes with geotextile tubes used in place of earthen dikes for the overflow section. To date, the geotextile tubes are in good condition, although their elevation is slightly lower than desired. Mr. McLellan indicated that tubes with a circumference of 22.5 ft were used and that larger tubes might have worked better.

The following are comments from discussions after Mr. McLellan's presentation.

Mr. McLellan stated that the installed costs for the Galveston District's projects roughly ranged between \$50 and \$150 per linear foot of tube. The range in costs depended on construction difficulty, location, and the cost of contract modifications, and whether tube construction was part of a scheduled dredging operation. Essentially, long tubes that are constructed in accessible areas where dredging is occurring are the least expensive. As the length of tube is decreased, the per foot cost may increase; as the accessibility decreases, the cost may increase; and if a dredge is mobilized solely to construct a tube, the cost will greatly increase. He noted that for his District, geotextile tubes were generally less expensive than rubble mound (or riprap) structures, but more expensive than earthen dikes. He said the best projects would incorporate a blend of the various dike options.

In each project, the tubes were filled with sand and were always placed on a firm, relatively level sand substrate. When asked about a time for filling tubes, Mr. McLellan said that the 400-ft-long tube at Port O'Connor took 9 hr to fill. However, only an 8-in. pipe was used in the process. Participants added that it took all day to fill three 300-ft tubes at another location along the Texas coast.

Representatives from contractors used by the Galveston District to construct some of the projects said that the tubes are constructed by rolling out the scour blanket and anchoring it with sand bags. Then the 18-in.-diam anchor tubes are filled with sand. The geotextile tube is placed on top of the scour blanket. As the tube is filled, workers walking on it help to flush out the muds leaving sand inside the tube. They said that when nothing but sand is left in the tube it is obvious because the tube becomes very hard.

Expected life of the tube is on the order of decades if vandalism and debris damage can be avoided. If the tube is exposed to direct sunlight, the ultraviolet light will weaken the fabric. However, if the tube is submerged or covered with algae, the potential degradation can be reduced or eliminated. If the filling sleeves are left open or if they open over time, then sediment can be washed out of the tube causing at least local deflation. Some participants have found success using large power line tie-wraps to close the sleeves. However, the movement of the sleeve back and forth over the tube in waves can slowly abrade the surface of the tube.

Topic II: Hydrodynamic Engineering Design

by
George Turk[1] *and Robert N. Blama*[2]

Load resistance factor design is the most important in design load determination. This includes the identification of load factors and strength reduction factors. The following equation defines design loading:

$$\gamma Q_w = \phi R_n$$

where

γ = load factor

Q_w = normal design load

ϕ = strength reduction factor

R_n = resistance

There are several loading types: quasi-static, wave-induced pulsating, flow, buoyancy, impact, and construction. Loading is variable with respect to both location and time and loading sources include waves (both shallow and deep water), tides, and winds as well as those created by man, such as during construction. Geotextile structure resistance to these various loading factors include gravity, friction (between fabric and the bedding it sits on), foundation, and fabric strength. The following discussion will focus on loading on the structure.

Several causes exist for failure of a geotextile structure. These causes include overturning and sliding of the tubes, forcing associated with waves including breaking waves, nonbreaking waves, and waves that propagate over the tube. Resistance to sliding can be determined by evaluating the normal force produced by gravity and the friction factor between the tube and the bed. Wave characteristics can be determined by using linear wave theory; however, wave loading varies with time complicating the problem.

Because of the various types of complex loading a geotextile tube structure can be subjected to, several approaches can be used to approximate them. Solutions to the Laplace Equation, based on linear wave theory, can be used to approximate pressure differentials needed to resolve quasi-static loads. Hydrodynamic pulsating loads can also be approximated by applying linear wave theory to both the Bernoulli Equation and the Morrison Equation, whereby dynamic pressure gradients, drag forces, and inertial forces can be resolved. Three methods that can be pursued to address impact loading are Minikin (1963),[3] Goda (1985),[4] and Homma and Horikawa (1965).[5] The Minikin (1963) approach discussed in Chapter 7 of the U.S. Army Engineer Shore Protection Manual (SPM) is recommended because it

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1 U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
2 U.S. Army Engineer District, Baltimore; Baltimore, MD.
3 Minikin, R. R. (1963). *Winds, waves, and maritime structures: Studies in harbor making and in the protection of coasts.* 2d ed., Griffin, London.
4 Goda, Y. (1985). *Random seas and design of maritime structures.* University of Tokyo Press, Tokyo, Japan.
5 Homma, M., and Horikawa, K. (1965). "Experimental study on total wave force against sea wall," *Coastal Engineering in Japan* 8, 119-129.

is a conservative approach. In fact, it may overestimate the structure loading by 15 to 18 times. The Minikin method addresses the wave impact on a vertical face seawall and can be modified to apply to geotextile tube structures. Refer to Chapter 7 of the SPM for more details on Minikin's method.

Geotextile tubes may be susceptible to sliding, overturning, or deformation due to local scour. The potential consequences of these responses need to be addressed in detail during the design phase of the project. Little or no research in the United States or abroad has been conducted on the forces on geotextile tubes; thus, the aforementioned design methodology provides only approximate solutions. Furthermore, forces have never been measured in the field or in the laboratory. There is a need to investigate and perform laboratory studies to evaluate the various methods available.

The first project undertaken by the U.S. Army Engineer District, Baltimore, in 1985 made use of impermeable Longard tubes, which are very similar to the geotextile tubes generally discussed during this workshop. The tubes were double lined to prevent permeability and add strength. The tubes were filled from one end while water was drained from the other end. Special hardware (flanges, connectors, etc.) were required to connect the dredge discharge pipe to the tube. A hopper dredge was used to fill the tubes. The project was constructed in 1985 in the southern portion of the Chesapeake Bay and is still functioning today. The tubes were used to limit wave action, offering quiescent habitat for the development of sea grasses. Three or four Longard tube projects are located within the Bay.

Eastern Neck National Wildlife Refuge, Chester River, Maryland. At Eastern Neck Wildlife Refuge in the Chesapeake Bay, a series of rubble mound segmented breakwaters were constructed in 1993. To aid in their performance, two additional breakwaters were constructed using geotextile tubes donated by the Nicolon Corporation. The segmented breakwater system was effective at helping to stabilize the eroding shoreline. The U.S. Fish and Wildlife Service was pleased with the effectiveness of the project and offered to purchase geotextile tubes for future projects that are currently being considered. Because of the success of the tubes at this site, the Baltimore District proceeded with three more projects where geotextile tubes were part of the design.

Mr. Blama discussed or referred to the three projects concurrently during the remainder of his presentation to highlight similarities and differences in deployment techniques and success. The projects were constructed within the last 2 years, so their success as retaining dikes and shore protection for dredged material is still undetermined. The projects are referred to as the Smith Island project, Barren Island project, and the Pokomoke River project.

Smith Island, Maryland. At Smith Island, 2,000 ft of continuous polypropylene tube with a 45-ft circumference and a tensile strength of 400 lb/in. was used to prevent continued shoreline erosion along a portion of the island. The tube served as a containment dike and as shore protection for dredged material placed to an intertidal elevation for the creation of wetland habitat. The project was constructed by the Great Lakes Dock and Dredge Co.

The unfilled tube was stacked accordion style on the back of a barge and was unfolded as it was deployed. Only a few hundred feet of tube was deployed at a time. The landward end of the tube was keyed into the shoreline. That is, a notch was dug into the shoreline that fit the end of the tube. This was intended to prevent flanking erosion at the end of the tube. An 8-in. dredge was used initially to fill the tube. However, the tube was difficult to fill to an adequate height supposedly due to a lack of filling pressure. Hence, the 8-in. dredge was upgraded to a 10-in. The tube was first pumped full of water to achieve shape. Then the dredge slurry was pumped. The tubes tended to twist in some locations during filing, but overall the tubes filled well. The final design height for the tube was expected to be 9 ft, but the actual height obtained was between 3.5 ft and 4 ft. The filling sleeves were spaced approximately 25 ft apart along the crest of the tube.

Mr. Blama indicated that the filling pipe had a 90° elbow connected to the end that was used to direct flows down the length of the tube. He said that it did not seem to work or help distribute material down the length of the tube, so it was removed. He also said that the deployment of the tube from a stack folded accordion style worked well. He supposed it worked as well as a deployment from a reel such as was presented by Mr. McLellan in a previous presentation.

Barren Island and the Honga River National Wildlife Refuge. At Barren Island, 36 geotextile tubes each 200 ft long and 30 to 37.5 ft in circumference were deployed to form a retaining dike for dredged material and for shore protection. Figure 3 shows the tube structure during construction. As at Smith Island, dredged material was placed to an intertidal elevation to create marsh habitat. Mr. Blama mentioned that the pumping distance for the dredge varied from 6,000 to 12,000 ft. He said that a 1,000-horsepower pump was used with a 14-in. suction pipe and a 12-in. discharge pipe. The material pumped was approximately 20-percent sand and 8-percent silt, which he did not think was high quality material for filling a tube.

The first six tubes that they filled burst, not on a seam, but in the fabric at the end of the furthest from the end in which they were filling. The fabric split on the first failed tube when the tube reached a height of 3 ft. The tube was only being filled with water at the time. The second failed tube split in the same location when filled initially with dredged material. Similar problems occurred at the Pokomoke site; so at that site, they tried putting a rip in the tube before filling to relieve the stress. This appeared to work. They decided the problem was caused by the type of dredged material and the dredge size being used, so they solved the problem by using tubes with higher tensile

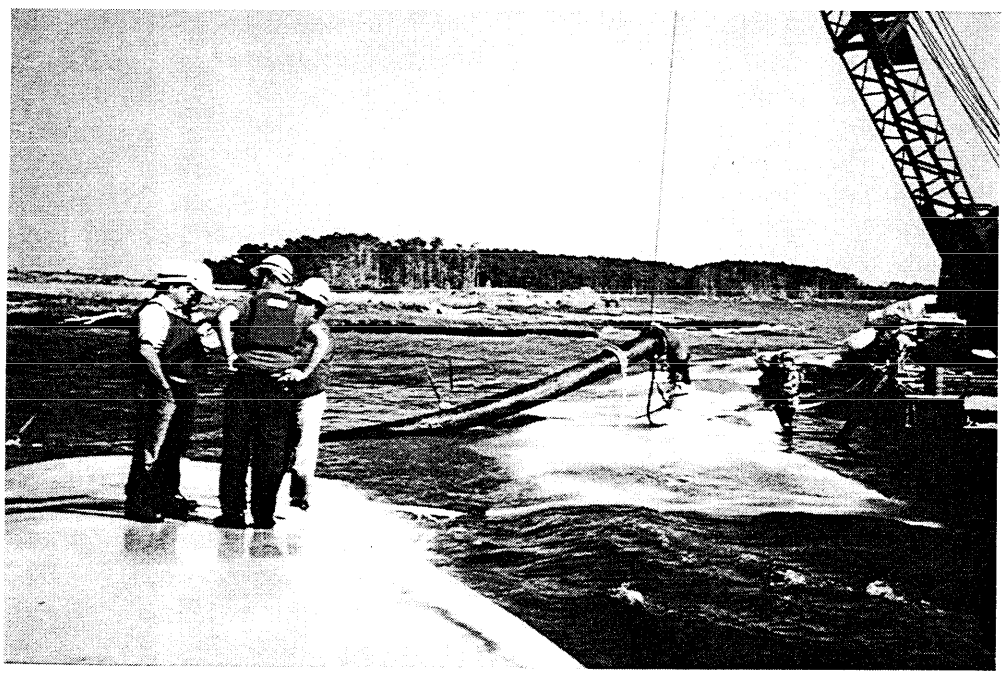

Figure 3. Construction of the geotextile-tube structure at Barren Island, Maryland, which is part of the Honga River National Wildlife Refuge

strength (1,000 lb/in.), a larger circumference (increased from 30 ft to 37.5 ft), placing an additional filling sleeve at the end of the tube where the ruptures occurred, and using a "Y" valve on the discharge line (i.e., one branch of the Y was directed to the inside of the placement facility and the other directed into the geotextile tube). This solved the problem of fabric tearing. The tubes were then filled at a rate of 4 ft^3/s, taking about 6 to 8 hr to fill one tube.

The plan was to install the tubes in 2 ft of water. However, tides made the actual installation depth closer to 5 ft. Workers standing in the water found it hard to work at this depth. The deployment was labor intensive, as up to six workers were required in the water to help unfold, hold, and stake down the geotextile tubes. The tubes had loop-straps that extended out from the sides of the tubes, through which long rebar stakes could be driven. The entire 200 ft of a given tube was deployed at once. Even though the tubes were staked in place, they tended to twist during filling probably due to the local waves and currents encountered at the site. Later during the construction, the contractor used 200-ft lengths of floating polyvinyl chloride (PVC) pipe to help unfold and shape the geotextile tube rather than stake down the edges. The PVC pipe was slipped through the loop-straps along the entire length of the tube. This held the upper half of the tube off the bottom while the lower half sagged. The approach required fewer workers in the water to hold the tube in place.

Mr. Blama provided some additional observations from the projects. First, while pumping, vortices form inside the tube near the pipe. The result is that sand does not settle well near the filling sleeve, causing a depression in the tube crest height at that location. Various deflectors and baffles attached to the end of the filling pipe to eliminate the vortices. It appeared that a baffle plate across the end of the pipe was the best option for the fine-grained sandy material being dredged at this site. In contrast, a contractor for the Galveston District noted that they could not get a baffle plate to work properly in their projects. He said that they used a flexible discharge pipe that could be oriented in any direction within the tube. They said it worked quite well.

Mr. Blama noted that the tubes at the projects achieved crest heights between 4 and 6 ft. He noted that at one point, dredging stopped due to storm conditions before a tube was completely filled. When dredging resumed, they found that the tube could not be pumped up any higher, resulting in a low final crest height. Mr. Blama cautioned that once filling begins, it should not be stopped until the tube is full.

Mr. Blama mentioned that a small hole was torn in a tube when the metal flange of a dredge pipe was dragged across the fully filled tube. A Nicolon Corporation representative onsite demonstrated how burlap can be placed in the hole to temporarily stop the loss of material.

Mr. Blama stated that the filling sleeves on the tubes were initially tied off with rope. They found that the rope would work loose in the waves. Hence, the Baltimore District asked Nicolon Corporation to sew pull cords into the filling sleeves such that when filling was complete, one could pull and tie the cord to close-off the sleeve. He noted that when water was coming out of the sleeves (as during filling), it took two or three people to sufficiently tie the sleeve. However, with the pull cords, it required only one person. Mr. Blama thought this worked well, but recommended that if possible the sleeves should be cut short and sewn closed. There is less chance for the sleeve to abrade the tube over time if it is cut as short as possible.

Mr. Blama mentioned that a few attempts were made to stack two tubes one on top of the other without success. They slid or rolled off of one another. Also as a result of this project, several other lessons were learned and improvements made. For example, the shipping of the geotextile tubes is an important consideration. Much of the abrasion that was noticed in the tubes during deployment was suspected to be the result of shipping and handling. Mr. Blama suggested that the manufacturer be required to mark the tubes as to their dimensions to prevent confusion during deployment. This is important when different sized tubes (length or circumference) are being used simultaneously in a project. The projects also indicated that sandy material is better for filling the geotextile tubes when trying to obtain a specific design height. When filling the tubes with silty material, the material tends to remain in suspension.

Bodkin Island, Maryland. The Baltimore District is currently planning to construct a geotextile tube project at Bodkin Island. The District is planning to stack a 30-ft circumference tube on top of two 37.5-ft circumference tubes. Good quality sand will be brought to the site by barge and pumped into the tubes. The stacked tubes will form a 4- or 5-acre circle. The area inside the circle will be filled with dredged material creating upland areas as well as high and low marsh. Offshore of the stacked geotextile tubes will be a smaller tube about 15 ft in circumference. The smaller tube will help to dissipate wave energy.

Finally, Mr. Blama stated that the success of a geotextile tube project depends on the following factors: dredge size, pumping distribution, tube lengths, tube circumference, fabric tensile strength, sediment grain size, and contractor attitude. The willingness of the contractor to construct geotextile tubes and find efficient and effective techniques for doing so was probably the most important.

Topic III: Geotechnical Engineering Design

by
John B. Palmerton [1] *and Wendell Mears*[2]

Following the difficulty experienced in releasing containers filled with dredged material at Marina Del Rey (refer to the presentation by Mr. Chuck Mesa), an analytically based, two-dimensional distinct element (DE) computer program was developed to simulate the behavior of soil-filled containers during the exit from a scow. Within this formulation, the soils placed within the container were represented by independent disc-shaped elements, and the container fabric is represented by similar, but connected, elements. The container is completely flexible and may change shape during the scow exit process. The following factors may be included as variables during the calculations: self-weight (gravity), externally applied loads, viscous drag forces, water depth, material strength parameters (i.e., cohesion and angle of internal friction), grain-size distribution, material density, fabric elastic properties and tensile strength, and scow geometry. The output of the code includes the shape and position of the container and its contents at any time step and the value of the tensile forces between the elements that form the fabric of the container. A schematic representation of the graphical output of the computer program is shown in Figure 4.

The results of the simulations for the Marina Del Rey project closely agreed with the actual experience. That is, the simulations indicated that the container would not exit the scow unless extra (folded) fabric was placed on the bottom of the scow, and then, assuming reasonable values for the friction angles of sand to sand and fabric to steel, expulsion of the container would occur only for scow volumes in the neighborhood of 1,500 cu yd or less (as was eventually ascertained in the field). The simulations also indicated that the fabric tensile forces approached the tensile strength for container volumes that would not exit the scow.

In addition to the simulation of the Marina Del Rey container drop, the DE code model was modified to simulate the sand-filling of tube-shaped (37-ft-diam, 500-ft-long) containers placed by the Baltimore District near the shore of Barren Island in Chesapeake Bay (refer to presentation by Mr. Robert Blama) and to simulate the behavior of tubes that solidify after filling (e.g., grout-filled tubes).

The simulations of the filling of the tubes at Barren Island agreed closely with the actual field experience. For these simulations, "sand" particles were sequentially injected into the deflated tubes at a given pump pressure until the tensile forces and weight of the sand became sufficient to stop any further injection. As expected, an increase in dredge pumping pressure caused the tubes to attain a higher final height (and to also achieve higher tensile forces in the container's fabric). It was also demonstrated that a lessening of the angle of internal friction between the sand grains also permitted higher tube heights to be achieved for a given pump pressure.

Although there was no verification with field data, the simulation of tubes filled with grout demonstrated the potential of the DE formulation to be applied to single and multiple tubes

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1 U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
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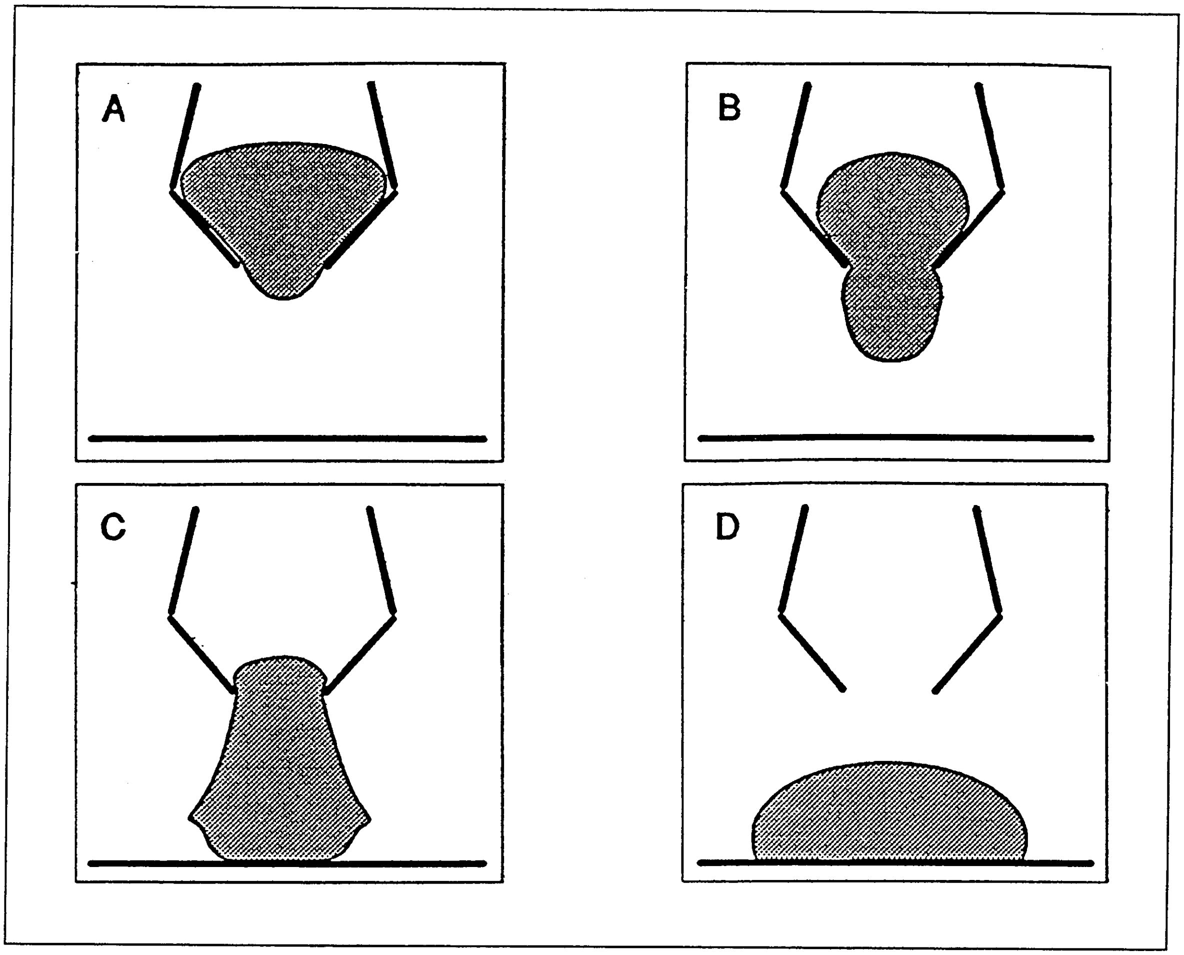

Figure 4. Schematic of model output for a container being dropped from a split-hull scow

(e.g., stacked tubes) that contain solid, granular, or slurried materials. The emphasis for these simulations was the inclusion of applied external forces (such as collisions of objects on the tubes or wave forces). This formulation for analyzing multiple interacting containers (or tubes) provides a means to assess the stability of structures composed of geotextile containers or tubes.

Mr. Mears stressed two important points. First, with regard to the Corps of Engineers, he noted that it has taken a long time for the Corps to develop its reputation for quality coastal engineering projects. He stated that geotextile tubes offer cost-effective capabilities for some projects, but cautioned that the Corps' reputation could be tarnished by poorly planned, designed, or constructed projects. He reiterated a point that Mr. George Turk had made in an earlier presentation that our ability to design geotextile tubes based on known or expected coastal processes is extremely limited. His second point, was that Districts alone cannot afford to study geotextile tubes sufficiently to increase our understanding for their design and construction. He stated that special funding directly from the U.S. Army Corps of Engineers Headquarters or from some of the Corps research programs is needed.

The project Mr. Mears was most familiar with was the Galliard Island project previously presented by Dr. Jack Fowler. He said that his District has been pleased with the project and intends to use geotextile tubes for additional applications, in particular cross dikes for the facility. He noted that every foot of elevation they can garner over the 1,300-acre site gives them about 2.5 million cubic yards of capacity. They want Galliard Island to function as a placement facility for another 70 years and must be sure that their designs today will not limit the project in the future. Hence, they need more information about the response of geotextile tubes in the coastal environment. Referring to the Gailliard Island project, Mr. Mears said the geotextile tubes placed on top of the dikes have continued to consolidate. Hence, the crest elevation of the dikes is changing. He also noted that the trench that was dug to help cradle the geotextile tube during construction helped stabilize that portion of the dike and gave the tubes significant longitudinal stability.

Topic IV: Geotextile Characteristics

by
Edward Trainer,[1] Charles Thompson,[2] Lee Harris,[3] and Chuck Mesa[4]

Geotextile fabrics are either woven or nonwoven. Nonwoven fabrics are either fused (spun continuous filaments placed randomly and fused with heat) or mechanically processed with needle punching. Woven fabrics have an orderly placement of yarn and are processed on large industrial looms. The fabrics are made of various types of polymers with the yarns finished for processing. The polymers used include polyethylene, polypropylene, and polyester. Polypropylene and polyester are the most popular fabrics largely because they are abundantly available. They are also low weight, have high strength-to-weight ratios, and are durable. The fabrics differ in tensile strength, with polypropylene having a strength of 400 lb/in. and polyester 1,000 lb/in. Polypropylene is more susceptible to ultraviolet (UV) light degradation than polyester. In fact, polypropylene requires application of a UV inhibitor to the fabric during manufacturing, while polyester does not. A participant added that polyester decays in an orderly way. But polypropylene decays slowly at first until the UV inhibitor is worn off and then decays much more rapidly. Polypropylene floats, while polyester sinks. The fabrics are durable in that they resist rot and mildew, do not react with soil or groundwater chemicals, and are not affected by low temperatures. Mr. Trainer was not sure whether long-term studies of the effects of seawater and marine organisms on the fabrics have ever been conducted. Most people noted, however, that several geotextile tubes have been in place for years and still appear intact. A participant noted that degradation is not necessarily bad, especially for wetland projects where deterioration of structures might be beneficial. It was also noted that the tube requires the most strength during filling. Once the tube is filled, the fabric could lose some of its strength (e.g, due to UV degradation) without compromising the integrity of the tube.

Mr. Trainer noted that UV tests have been performed on the fabrics by exposing the fabric to UV light more intense than sunlight for 500 hr. After the tests, the fabrics had lost 20 to 30 percent of their initial strength. At present, there is no way to extrapolate degradation rates in accelerated laboratory tests to degradation rates in the field. A participant added that the American Society for Testing and Materials (ASTM) is developing an outdoor exposure test that will provide more information about survivability of fabrics in the field. Mr. Trainer stated that algal growth and sediment deposition on the fabrics reduces the penetration of UV light and limits the level of degradation. A participant provided an example where nylon bags submerged in shallow water have survived for 22 years in the field ostensibly because they have become completely covered in marine growth. The few nylon bags that have not been continuously submerged have deteriorated.

Mr. Trainer said that the circumference of a tube is often dictated by the widths of the fabric sheets used to construct the tube. That is, if two sheets of 15-ft-wide fabric are used, the tube circumference will be about 30 ft. However, any circumference specification can be

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achieved by cutting sheets to size. He said that Nicolon has manufactured tubes that are from 100 ft long up to 2,000 ft long.

Filling sleeves are manufactured into the tubes with the spacing specified by the buyer. Spacings from 25 to 100 ft are common. When a tube design requires a liner to retain fine material, a nonwoven fabric is generally used. In past projects, an 8-oz. weight polypropylene fabric has been used.

Mr. Trainer discussed patching fabric damaged in the field. He noted that 3M marine adhesive #5200 worked well to bond a patch to fabric. The adhesive appears to work well under both wet and dry conditions. A participant added that, in the dry, they had success with off-the-shelf 3M adhesives. They would place a patch bigger than the hole inside the tube and a patch bigger than the hole on the outside and adhere them together. Burlap can be used on small holes or tears to temporarily stop the loss of fill material. A piece of burlap larger than the hole is placed on the inside of the tube. However, the burlap will decay and cannot be considered for long-term solutions.

It is unknown whether any studies have been performed in seawater to evaluate chemical and biological effects; however, analyses of the effects of contaminated material and biological colonization are being performed. When the tubes tear, do they unravel? If they do, how quickly? There have been problems encountered with grass growing between the layers of fabric in geotextile tubes when the tubes are lined.

Participants noted that more information is needed about which organisms are inclined to grow on the tubes and which organisms are inhibited by tubes. For example, are boring organisms inhibited by synthetic fabric on the seabed. Or, in cases where contaminants are being contained in tubes (refer to Mr. Chuck Mesa's presentation), are boring organisms capable of permeating the tube, hence, lessening the tubes integrity.

A participant asked whether geotextile tubes can be placed over shallow-water stump fields. Most people responded that it is not recommended because the stress on the fabric would likely cause a tear. Some noted that they have placed geotextile tubes over stumps requiring that the stumps be cut smooth to less than 12 in. above bottom. If the tube is punctured from the underside, it may still function well. However, if a stump punctures the side of a tube, it may result in loss of fill material.

Mr. Thompson has worked in the Riverine and Coastal Section of the Hydraulics and Hydrology branch of the Detroit District for 16 years. Mr. Thompson's duties include the evaluation of the effects of coastal structures (in both Federal and non-Federal projects) on the shorelines of the Great Lakes. He noted that even before he began working with the District, geotextiles had been used in shoreline protection projects on the Great Lakes. In fact, he referenced the U.S. Army Corps of Engineers' studies of shoreline protection in the 1970s, often referred to as the Section 54 studies. In that study, geotextiles were tested, including a Longard tube revetment in Lake Michigan and sand-bag groins and breakwaters. He noted that in that study, the geotextiles met with little or limited success. He emphasized that because of this history and experience with geotextiles, it did not seem appropriate to consider geotextiles in coastal engineering as "innovative." (Editors note: Mr. Thompson was referring to the invitation sent to participants that referred to geotextile tubes as an innovative technology for coastal engineering.)

Mr. Thompson described the wave climate of the Great Lakes as often quiet, but that in storms, wave heights of 5 to 6 ft are not uncommon, making the wave climate of the lakes similar to that found along the shores of the Gulf of Mexico and some of the protected areas of the Atlantic and Pacific coasts. He described the shorelines of the Lakes as being composed mostly of glacial tills. Many stretches of shoreline are bluffs fronted by beach. The lake bed nearshore is a mixture of sands and gravels. Sometimes the nearshore is exposed clay with a patchy covering of sand and/or gravel. The water levels in the Lakes also fluctuate from year to year.

Mr. Thompson said that because of the sometimes intense wave climate, composition of the shoreline and nearshore lake bed, and varying water levels, it is difficult to construct shore-protection structures. He noted that because of the lack of strict regulations on the design and construction of shore protection, many technologies and techniques have been tried—many of them failing after a few years. In reference to geotextiles, he noted the structures that have been built (mostly groins and revetments) from geotextile bags filled with grout. The bags are usually about 4 ft in diameter and 10 ft long. He said that within a few years, most of the structures fail for one or a combination of the following reasons: the fabric tears away from the bags, exposing the grout to deteriorating or destructive forces; the bags are displaced; the bed scours in front of the structure, and the structure collapses; the structure differentially settles into the foundation; ice damages and displaces the bags. He said that almost none of the bags are filled exclusively with sand because they deflate very quickly once punctured. He noted that vandalism to the bags is common and that the presence of ice and debris (trees and large branches) easily damages the fabrics.

Mr. Thompson said that in general, he was not a proponent of structures to eliminate shoreline erosion, but that based on his observation, he did not think that fabric bags filled with grout did any better or worse than most of the other types of structure used in the Great Lakes. His conclusion is that the Great Lakes are not a good place to use fabric bags.

The following comments were made during discussion.

Many of the participants noted the difference in characteristics of the bags Mr. Thompson referred to and the larger geotextile tubes discussed in previous presentations. Most thought that long sand-filled tubes of high-strength fabric would respond better than small (4 by 10 ft) grout-filled bags of unknown fabric strength. Mr. Thompson noted that he presented what he has observed on the Great Lakes and noted that failures are often due to processes of scour and settlement, which could detrimentally affect any structure. It was added that fabric scour blankets used in the Great Lakes have also deteriorated quickly. It was noted that as the anchor tube on the edge of the scour blanket buried, the blanket would form a convex curve. The surface of the blanket was then vulnerable to abrasion by debris and the constant agitation of sand and gravel by waves.

A comment was made that anyone using sand-filled geotextile tubes or bags without the expectation that it was temporary, would simply be fooling themselves. Some participants noted that geotextile tubes have been used as temporary erosion protection prior to the construction of other protection measures. For example, a geotextile tube was placed along side of the south jetty at Port Canaveral, FL, to prevent sand leakage into the inlet prior to reconstruction of the jetty. At Vero Beach, FL, a geotextile tube was buried in a dune. It remained hidden until a storm struck and removed sand from the dune. During the rest of the storm, the geotextile tube served as protection against the waves. Mr. Thompson noted that most of the shore protection structures that he discussed or referred to were built by private landowners and that he was sure none of them built their structures with the understanding that they were temporary.

Geosynthetic fabrics used for sand-filled structures can be divided into three classes: (a) geotextiles, (b) geogrids, and (c) geomembranes. Geotextiles are permeable and porous, retaining sand-size particles and larger when filled. Geogrids are a coarser weave and are designed to retain larger particles such as rocks in a gabion structure. Finally, geomembranes are impermeable fabrics that will retain anything that is placed inside—sediment, water, or air. Geomembranes can fill very quickly, and a relief port is required to expel air and water when used for a sand-filled structure. For example, if the geomembrane is being filled with sand-water slurry, a relief port would be used to decant the water. Dr. Harris mentioned some applications where geomembrane tubes were filled with water only and served as temporary protection while a more permanent structure was built. He reiterated previous comments that geotextile containers filled with sand are not new, but noted that today's fabrics, protective coatings (e.g., UV inhibitors), and available sizes are an improvement over those previously used.

Geosynthetic tube structures have been used for shore protection and scour protection on the open coasts of the Atlantic and Gulf of Mexico. For example, on Jupiter Island, geotextile bags were used as temporary or emergency toe protection for a seawall until improvements could be made. Dr. Harris found it convenient to categorize sand-filled structures as composed of (a) individual containers, (b) vertically stacked containers, (c) sloped-mound containers, and (d) sloped-revetment containers. He also noted that containers came in many shapes and sizes in contrast to the geotextile tubes discussed previously, which were large, single, round containers. He mentioned a tube marketed as the Protec-Tube (patent # 4,966,491) which is compartmentalized. The compartments run the length of the container. If any one compartment is damaged, the integrity of the whole structure is not compromised. Also, the compartmentalization makes the tube fill to a designed shape that reduces its tendency to roll when filled. Dr. Harris suggested that with today's fabrics and manufacturing techniques, we should be able to design fabric-sand structures with great resistance to wave forces and the effects of coastal processes.

Dr. Harris showed many case study slides that are not possible to describe here. However, a few of the projects he discussed are summarized here. Dr. Harris stressed in almost all of the projects, failure occurred because the structures were undercut by scour. Subsequently, the bags or tubes rotated toward the scour holes, toppling the structures. He said that straps were sometimes used to hold stacked tubes together. But in general, he said they were not effective. He noted that the cost of most of the projects discussed probably cost about the same as an equivalent project made from riprap. Much of the costs came from transporting sand to the sites to fill the bags and tubes. (Editors note: Recall that in previous presentations, it was mentioned that costs were comparable between geotextile tubes and riprap structures. The geotextiles were generally only cheaper when used in conjunction with a scheduled dredging operation, so that fill material is essentially delivered to the site at no cost.)

An early application presented was the backshore sill, as shown in Figure 5. This structure was built from groups of three tubes stacked (one row atop two bottom rows) and strapped together by nylon webbing that went completely around the stacked configuration. Typical structure segments employed ranged from 10 to 40 ft. The structure was buried. During minor storms, the tubes effectively protected the shoreline. The tubes would uncover during the storm, but the beach would recover during milder conditions. However, during a major storm, the tubes were completely uncovered, some scour occurred in front of the structure, and the bags fell over. No upland erosion had occurred at the site until the structure began to fall over. Dr. Harris pointed out that because of Florida permitting rules, small structures were typically constructed. These structures typically could withstand 5 to 10 years of storms. Larger storms required much larger structures covering more of the beach profile. But, large structures require special permitting that was very difficult to obtain.

In 1985, several backshore sills were installed at Vero Beach. These projects were uncovered in 1995 by Hurricane Erin, but

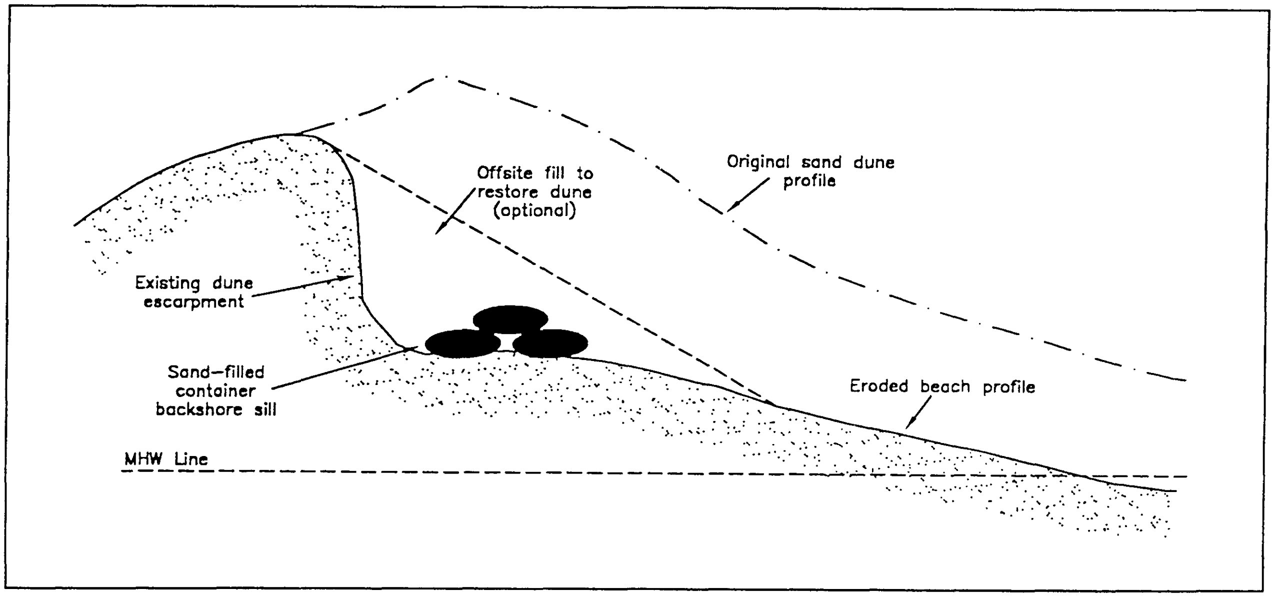

Figure 5. Schematic of stacked tubes forming a backshore sill

upper part of the structure segments. The pipes are tied together with a strap system that underlays the segments. The tubes when looked at in effectively protected the shoreline providing toe-scour protection to the dune. In contrast, other projects that had been in place less than 1 year have failed due to undercutting of the foundation.

The latest development in sloped-revetment systems is the Subsurface Dune Restoration System (SDRS, patent # 4,919,567) shown in Figure 6. Projects in Palm Beach and Indian River counties in Florida and Myrtle Beach, South Carolina, were constructed in 1988-1989 and have been very successful. These systems used polyvinyl chloride pipes placed in the cross section were shaped somewhat like a tear drop, i.e., thinner near the upslope edge of the tube and thicker at the downslope edge of the tube. Once the tubes were installed, they were covered with fill material. The Myrtle Beach project was constructed using four rows of tubes in the teardrop configuration. The project was completed just before Hurricane Hugo struck. The area was inundated by several feet of storm surge and survived.

Dr. Harris noted that in the 1970s, a project was installed in Melbourne County, Florida. A black filter cloth fabric was sewn together to make a tube. The structure was finally damaged in 1989 during a storm. He noted though that many other riprap structures also suffered damages from that storm. In Martin County, Florida, in 1983, a structure made from eight rows of teardrop-shaped tubes was installed. The system was uncovered in 1984 during the most erosive storm to hit the area in 50 years. The structure survived. But in 1988, the structure was finally undercut and damaged. A participant noted that any gravity structure placed on a beach that is in a process of downcutting is in extreme danger of being undercut.

Dr. Harris described a project constructed in 1989 at Vero Beach, Florida, where a 15-ft-high revetment was constructed in stacked revetment of 14 geotextile tubes. Each row layer of structure was a single continuous tube. The longest tube was on the bottom and was about 460 ft long. The project had a mild convex curvature to minimize flanking erosion problems. The toe of the slope was at 0 MLW with the crest at about +15 ft MLW. The slope was 1V:3H.

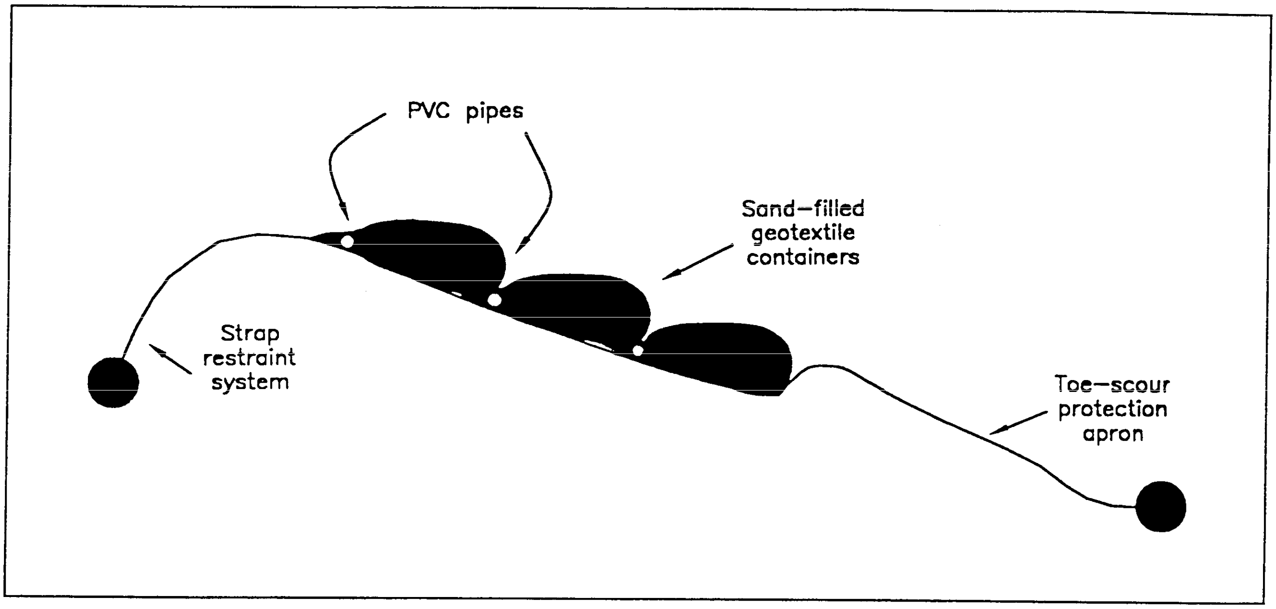

Figure 6. Schematic of the patented Subsurface Dune Restoration System

After construction it was covered with sand and vegetated. After Hurricane Erin in 1995, three rows of the tubes were slightly exposed, but no damage occurred.

Dr. Harris described the Protec-Tube placed on Longboat Key, Florida (Gulf of Mexico), in 1988. The tubes had three compartments. The cross section of the tube was somewhat wedge-shaped with the landward side of the cross section thicker than the seaward side. The inner fabric was impermeable with a coarse-weave outer protective layer. The tube was first filled with water to get the shape, and then sand was introduced. The project has suffered only minor scour problems and has protected the upland area.

Dr. Harris noted that a beneficial feature of geotextile structures used as revetments is that they are easy for pedestrians to cross, whereas riprap can be dangerous. Another advantage of sand-filled structures is that if they are damaged, the beach is just covered with sand, which does not interfere with anyone's enjoyment of the beach. However, when riprap structures are damaged, rocks distributed over the beach can cause trouble for the public.

The maintenance dredging project at Marina del Rey involved removal of approximately 57,000 cu yd of contaminated sediments from the navigation channel. The sediments were excavated with a clamshell dredge and placed in a split hull scow. The scow was lined with geotextile fabric (Figure 7). After the sediments were placed in the scow, excess fabric was folded over the top and sewed closed so that the sediments were enclosed in a fabric container, commonly referred to as a geotextile container. The geotextile containers were transported offshore to a placement site and dropped out of the bottom of the split hull scow (Figure 8). This project was the first use of geotextile containers for containment of contaminated dredged sediments.

The project was conceived and implemented jointly by the U.S. Army Engineer District, Los Angeles, and the U.S. Army Engineer Waterways Experiment Station (WES). The local sponsor for Marina del Rey was the Los Angeles County Department of Beaches and Harbors. The local sponsor for the placement site was the Port of Los Angeles. Federal, State, and local entities involved in this study included the 36th U.S. Congressional District

Figure 7. Geotextile liner inside a split-hull scow used in the Marina del Ray contaminated material containerization project

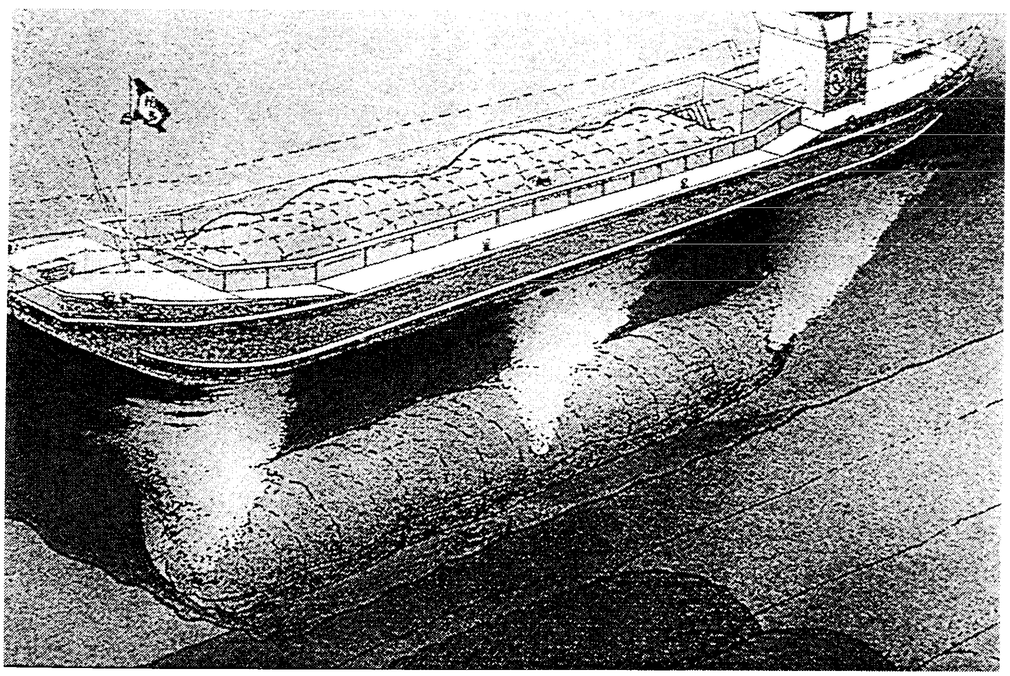

Figure 8. Artists rendering of a geotextile container being dropped from the bottom of a split-hull scow

Office, the U.S. Environmental Protection Agency, the U.S. Fish and Wildlife Service, the National Marine Fisheries Service, the U.S. Coast Guard, the California Coastal Commission, the California Department of Fish and Game, the Southern California Regional Water Quality Control Board, the 4th Los Angeles County District Supervisors Office, the Los Angles County Department of Public Works, and the Heal the Bay (community).

The dredged material consisted of poorly graded sands and silty sands. The sediments contained approximately 8-percent silt and clay-sized particles. Chemical analysis of the in situ sediments indicated that copper, lead, zinc, oil and grease, and total recoverable petroleum hydrocarbons were present in significant concentrations.

The geotextile containers had two layers of fabric. The outer layer was woven polyester, and the inner layer was continuous filament, nonwoven polyester. The woven fabric provided strength, while the nonwoven fabric reduced the permeability of the container. The maximum fabric stress occurs when the container is released from the scow and the bin is fully open. The container strength was therefore selected such that it could carry all of the stresses that would occur during release. Note that the inner fabric also contributes to the container strength. The permeability of the nonwoven fabric was selected to retain 100 percent of the fine-grained particles up to the #230 sieve.

Physical model tests were conducted at WES to qualitatively demonstrate the concept of geotextile containers. A 1:25 scale model split-hull scow in an 8-ft-deep pool was used to observe total system behavior during split-hull scow release of the containers, observe the geotextile fabric system effectiveness in containing the sediments during fall through the water column, and observe container behavior during bottom impact. The model test results were instrumental in demonstrating the feasibility of geotextile container technology to the governing regulatory and/or environmental agencies.

Effluent suspended solids and chemical concentration tests were conducted as well. A sample of native sediments was passed through a 2-m-diam centrifuge for 3 hr at 91 g, representing 3 years of loading in the field. The resulting elutriate was tested and suspended solid concentrations ranging from 2.57 to 3.70 percent were found, which compares well with the 2.5 to 3.0 percent typically found in seawater. The filtered elutriate also contained acceptable levels of each concerned chemical constituent.

During dredging, turbidity was controlled and water quality was monitored to comply with local water quality requirements. Turbidity and floating debris were minimized by using a closed bucket clamshell dredge and conventional silt curtains. Use of the clamshell dredge also reduced the water content of the material placed in the scow. Floats were placed inside the containers to indicate whether the container ruptured during placement. If a rupture occurred, a float (highly buoyant and visible object) would escape the container. Observers on the scow watched for floats as the containers were placed.

Scows were modified to meet a required 2:1 (maximum) top of bin-to-bin opening ratio. To this, false bulkheads the length of the hopper were installed essentially to reduce the width of the bin. The scow bin capacity was limited to 3,000 cu yd. An industrial sewing machine used to close the container after filling was wheel mounted and required construction of a walkway along the scow sides. A 1-ft/s bin opening rate was desired, but could not be achieved by the scows.

The first geotextile container held 1,900 cu yd of dredge material removed in a 20-hr period. The dredge bucket cycling time was about 3 min because (a) the leverman maneuvered the clamshell slowly to prevent damage to the geotextile fabrics, (b) each bucket load was fully drained of water prior to placement within the scow, and (c) the sediment type (coarse granular sand) was difficult to dredge. Sewing the first container shut was also difficult because rain saturated the nonwoven fabric making it heavy. Hence, the labor required to close the container was increased and required 7 hr.

The first container became lodged in the scow as the bin opened. The container dropped 3 to 4 ft and stopped. Several techniques were tried to release the container, including cutting the scow's geosynthetic bulkhead liner, massaging the container with the jaws of the scow's bin, using prop wash to vibrate the container, surcharging the container by flooding the hopper with water, and fluidizing the encased sediments. Ultimately, fluidizing the sediments in the container dislodged it from the scow.

After modifications (identified below), 43 more containers were filled and placed without incident. The final delivery rate to the placement site averaged 1.5 containers per 24-hr day. Scow positioning prior to release averaged 10 to 15 min, and final container release times averaged approximately 60 to 75 s.

Several project modifications were implemented to optimize cycle time and to ensure subsequent containers would not lodge during disposal operations. The hopper interior polypropylene woven fabric liner was permanently removed to minimize friction between the geotextile container and the bin bulkheads. It was determined that the fabric type used actually increased friction due to surface roughness. Note also that the bin was inspected to be sure it was free of burrs that might otherwise damage the geotextile fabric. The circumference of each container was increased from 90 to 120 ft to provide more sediment mobility during container release. The extra fabric was accordion folded into the bottom of the bin. The volume of material placed in each container was reduced. The optimal volume was about 1,300 cu yd. The scow was loaded differentially along its length as well, such that one end of the bin was filled 2 ft less than the other. This increased and improved the flow of water into the bin. The seam used to close the container was altered to speed up operations. Originally, a "J" seam (two layers of fabric folded over, total of four fabric layers) was used. But later, a "prayer" seam (two fabric layers) was used. This decreased the total sewing time and decreased the number of malfunctions in the sewing machine at no loss of seam strength to the container system.

Topic V: Risk and Contingencies

by
Mary C. Landin[1]

Dr. Landin began her presentation by noting that the Corps and its customers will continue to dredge to maintain navigation and flood control and as part of the permitting process for U.S. Navy homeporting, private and public marinas, and other reasons. While the Corps dredges approximately 350 MCY annually, only a tiny fraction of this has been considered for use in tubes or involves tube projects. However, the low costs associated with using tubes as breakwaters for beneficial uses of dredged material projects have made it an area of intense discussion and concern. There are a number of risks and contingencies associated with the use of tubes that have been discovered as part of projects and dealt with, some successfully and others not. Since virtually all of the tube projects in which she has been associated have involved fish and wildlife habitats, threatened and endangered species, and other natural resource restoration, the environmental risks had to be considered in planning, design, and implementation of tube projects.

In years past, the Corps generally used unconfined disposal of dredged material with a primary purpose of navigation and channel maintenance. However, a secondary purpose resulted in the creation and/or restoration of numerous fish and wildlife habitats on the dredged material islands, wetlands, and other sites. Successful examples include Bird and Sunken Islands, Tampa Bay, Florida, where 60+-year-old dredged material islands resulted from channel construction, and the islands were given to the National Audubon Society (U.S. Army Corps of Engineers, 1987). They now have over 35,000 pairs of nesting waterbirds on them annually and have resulted in a great environmental plus in every way. There are a number of similar examples that could be used.

However, some of the projects built that have resulted in excellent habitats have not been well received due to misperception by resource agencies and environmental groups. For example, the only new salt marsh in South Carolina was being constructed on unconfined dredged material in Winyah Bay since 1974. It is much more productive than the natural salt marsh in the vicinity to which it is being compared (LaSalle, Landin, and Sims 1991). The difficulty is that the Federal and State resource agencies believe (without basis of fact) that fish and benthic organisms are being impacted by the unconfined material and will not be persuaded otherwise. This has jeopardized Charleston District's navigation project, and the loss of the project would jeopardize the natural resource benefits accrued with the new marsh. Since the District has had to stop putting dredged material at the site during cycles, the marsh has begun to erode.

In still another example of the twists and turns that dredging projects can take, the Corps built an island to create wetlands and uplands in the James River, Virginia, in the early 1970s. All of the resource agencies and environmental groups thought it was a great idea and signed off on the location and design of the project. Unfortunately, the design and siting were flawed. The project was constructed and remained in place as fresh marsh for approximately 10 years; then during a major, prolonged flood on the James, the site failed and most of

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the marsh floated off (Landin, Webb, and Knutson 1989). The consequences of improper siting, failure to locate the weir in the best place, failure to use the best choices of plant materials, and other problems have been great. Not only did the Corps lose its site, but any chance of a new project in the area has been lost due to the negative reactions of State and Federal officials.

This leads us to tubes and why we are attending this workshop. Tube technology is new and rapidly evolving, although tubes and bags have been used for over 20 years on project sites. There is substantial risk in jumping headlong into habitat-related tube projects without careful consideration of the ramifications of design, implementation, and potential short-term and long-term success. The Corps does not need more projects that ultimately failed or that were never accepted; rather, we need to be proactive in making natural resource projects with tubes be successful and in educating others on the technology and its potential for shoreline stabilization, habitat restoration, beach protection, and other opportunities. To illustrate some of the risks and contingencies likely to be encountered, Dr. Landin identified and discussed 10 Corps dredging projects that used geotextile tubes and noted the environmental benefits and/or consequences of each.

Bolivar Peninsula, Texas. This site has been previously brought to the attention of the workshop, but Dr. Landin felt it important to note some of the environmental aspects. This research site built in the early 1970s on Goat Island off Bolivar Peninsula used geotextile sand-filled bags 10 by 3 by 3 ft in size that were filled and stacked in place to the high tide line to protect the planned wetland restoration site from a 26-mile wind fetch that had prevented wetlands from growing on an old dredged material deposit. The bags were not lined, causing the fine-grained sand to seep out, and they had to be refilled using liners. The original design called for these bags to be temporary, and this was one of the first wetlands the Corps built purposely. It was assumed that the bags would be sacrificial, and that once the experimental marsh had established, it would not matter what happened to the bags (Landin, Webb, and Knutson 1989).

As it turned out over time, the marsh successfully established after planting and grew well, but not without the aid of the bag breakwater. Wave energies were too strong to hold the site without a permanent breakwater, but the breakwater did not disappear as the Corps expected. Instead, it colonized with oysters and became an intertidal oyster bed. The oysters protect the bags from UV light. The unexpected environmental benefits gained from the large bags are still being achieved and belatedly recognized by resource agencies and environmental groups in Galveston Bay. The long-term success of this site has outlasted skepticism that man-made wetlands will not work in Galveston Bay and is being used to provide lessons learned and information to the Houston Ship Channel Deepening and Widening Project now in initial stages. The site has provided habitat for a number of wildlife, fish, and invertebrate species in much greater numbers than envisioned at construction and compared favorably to three natural marshes with which it was compared. Since this was a research site, the risk taking here was minimized for the Corps (research sites are supposed to have some unknowns). However, the Corps had no contingency plan of action should the site have failed.

Core Sound, North Carolina. The Corps built two islands for seabird nesting in Core Sound in the Atlantic Intercoastal Waterway (AIWW) in 1979 using maintenance dredged material. The islands were well planned, designed, and implemented. The environmental input by regional universities, National Audubon Society, and State and Federal agencies was very positive. The Corps used the same types of geotextile bags as were used in Bolivar Peninsula to form kidney-shaped configured islands that were filled with sand dredged material. Terns and skimmers began to nest on the islands prior to actual construction being completed. The bags functioned exactly as expected, and salt marsh fringes were planted on their seaward side (Landin 1992; U.S. Army Corps of Engineers 1987).

One island is still highly successful, and thousands of seabirds nest on it each year. The second island, while planned, designed, and built with the same expectations of success as the first island, failed completely. Why? Technology and engineering aspects were highly successful. However, no one took time to explain to the local fishermen that the nesting seabirds would not eat all of their catch, and they slashed the bags to sabotage the islands. The island that failed had not had sufficient time to consolidate, and washed away. Risk taken: huge outlay of funds to properly build and protect dredged material islands that resulted in a 50-percent failure. Lessons learned: never take for granted that everyone is happy with a project, and put a lot of emphasis on education and consensus building. Again, the Corps had no contingency plan when one of the islands failed. The fact that the bags and dredging performed impeccably did not matter in the long run on the failed site because nontechnical problems got in the way.

Foundry Cove, Hudson River, New York. The project has also been previously mentioned in this workshop. This is an intertidal marsh site in the Hudson River that became highly contaminated with cadmium. The entire wetland had to be removed, clean soil brought to the site, and the wetland rebuilt to satisfy environmental and mitigation requirements. It was an extremely expensive undertaking, and was primarily funded by the U.S. Environmental Protection Agency (EPA) as a Superfund site. However, the Corps was involved in technical aspects.

To hold back a 3-ft tide and work in the "dry," a 2,000-ft-long by 45 ft in circumference water-filled impermeable tube was anchored at each end of the wetland, and pumps worked continuously to maintain a "dry" site. The center of the long tube began to roll with the tidal action, and had to be shored up with loads of earth dumped on each side of the tube. This work was taking place simultaneously with the excavation of the contaminants and rebuilding of the wetland. Should the tube have failed, the risks were safety, drowning of the site, redistribution of the cadmium into the Hudson River, loss of the wetland, bad public relations problems in a highly visible project and heavily used recreational river, and much wasted money. As it turned out, the "quick fix" with dump trucks by the site contractor was sufficient to hold the tube long enough for the wetland to be rebuilt as planned. However, once again, the EPA, Corps, and State of New York did not have continency plans should the tube fail.

Gulf of Mexico, Louisiana. In the Louisiana part of the Gulf where shoreline erosion as well as subsidence is destroying large tracts of wetlands and fast land, the State and the Corps have used detached riprap breakwaters primarily, but also tubes in attempts to slow erosion and to trap sediment to reform marshes and protect roads. Where these breakwaters have been placed in single rows in shallow water offshore, sediment is being trapped behind and forming tombolas. Where these breakwaters were placed in staggered rows that broke up nearly 100 percent of wave energy, sediment was being trapped at a much faster rate. These areas colonize as marsh and slow erosion that had been occurring. Not enough of this kind of work has been done in coastal Louisiana to determine how well tube use works over time, but the technique has a great deal of promise due to the nature of Louisiana sediments and foundations and the availability of borrow material to fill tubes. From a risk standpoint, Louisianans are willing to test almost anything with firm promise of erosion and subsidence control, and the environmental ramifications are positive.

Eastern Neck National Wildlife Refuge, Maryland. This project has also been mentioned earlier in the workshop, but has environmental aspects that require emphasis. The combinations of detached riprap breakwaters, detached geotextile tubes, backfilling to an intertidal elevation for salt marsh, habitat combinations, and tests of biodegradable fabrics to protect marsh plantings all came together to make this a highly successful project environmentally. Fish and wildlife use has been spectacular. It was partnered by the U.S. Fish and Wildlife Service, the State of Maryland, and the Corps, and the Service and the Corps assumed the risk on the project (Blama et al. 1995b). Since it was a maintenance dredging project and a demonstration partnership with the Service, the sociopolitical consequences of failure were not as great (such as for a regulatory mitigation project).

In the case of Eastern Neck, Baltimore District did have a contingency plan in mind when plans and designs did not work out exactly as envisioned. Their overall plan called for using maintenance dredged material as appropriate to add to and improve the site, as well as to repair any spots that were suffering erosion. They also had discussed with the Service the use of additional geotextile tubes using Corps funds and Service labor to plug erosion spots. When the cordgrass plantings in 1993 did not survive as well as desired after a very severe 1993-94 winter (ice floes 14 ft high over the marsh and tubes), the Corps had the same contractor plus large groups of volunteers come back and replant parts of the site. In addition, tests of biodegradable mat were made, and this proved to work very well against Chesapeake Bay erosive forces. All of these strategies and hands-on management were able to correct unforeseen problems encountered during construction.

Smith Island, Chesapeake Bay, Maryland. The previously discussed Smith Island project also had the potential for risk and consequences. The risks were related to continued erosion of the island, the perception by citizens that the Corps could not solve their island's problem, and achieving limited results for large expenditures. While the tubes did not fill as well as planned and designed, they currently provide adequate protection to the sand dredged material placed behind them for wetland restoration. Therefore, no postproject contingencies have been needed. However, during construction when one tube failed, the back-up plan was to place another tube on top of the first and fill it. This technique was successful. Likewise, when the smaller dredge pipe was inadequate, the back-up plan was to bring in a larger dredge. This technique, however, was too late to raise the height of tubes to the design elevation (Blama et al. 1995a).

Kenilworth Marsh, Anacostia River, Washington, DC. Dr. Landin noted that the Kenilworth Marsh project has not been discussed during the workshop. The site is part of the National Aquatic Gardens and owned by the National Park Service. However, the Corps paid for the project entirely. The site is a dredged material marsh built within the Anacostia River intertidal zone using water-filled tubes to both temporarily hold back the tide and hold the dredged material in place until it had consolidated and the site was planted. At that point, water was let out of the tubes, and they were removed to restore intertidal connection. The material was dredged as part of a flood control project, not for navigation. This project is within the Nation's capitol and is a highly visible, as well as highly successful, restoration project (Garbarino et al. 1995).

In Dr. Landin's opinion, the risk was entirely the Corps', as the Park Service was the land owner, but would still have a usable natural area without the wetland project. However, it would never have been attempted if the Park Service had not requested that the Corps help them. Partners on the project were the Corps, the Park Service, the U.S. Fish and Wildlife Service, and the District of Columbia Council of Governments. The tubes and dredged material performed exactly as designed. One difference of opinion was in planting of the wetland. Natural colonization was expected, based on similar projects in the past, to entirely vegetate the wetlands. However, the Park Service wanted to be sure the site would vegetate (lack of trust), so the Corps hired a contractor to plant the site with a variety of wetland/wildlife food plant species. Within weeks it was fully vegetated, primarily with nonplanted species (natural colonization from the dredged material seed bank). By the end of the first growing season, the wetland was dominated by non-planted species, and by the end of the second growing season, small wetland trees and shrubs were beginning to grow on the site. WES had predicted that the site will ultimately become floodplain forest, as that was what the habitat originally was. Into the third growing season, it is well on its way to becoming that.

There was no written agreement over the partnerships on the project, and now the Park Service is treating the project as if it was theirs solely and never mentions the Corps' very major role. This is always a risk is partnering and is hard to predict—this controversial problem has to be treated as a lesson learned. Technically, there was little risk; therefore, no real contingency plans were developed. In fact, the techniques of tubes and dredged material combinations were so successful at Kenilworth, the Baltimore District is planning a similar project at Kingman Lake, also within the Anacostia River floodplain.

Hart-Miller and Poplar Islands, Chesapeake Bay, Maryland. Hart-Miller Island is a confined disposal facility (CDF) built in the Bay and currently holding approximately 70 MCY of dredged material. Tubes have not been used for this nearly completed project. Hart-Miller CDF is based on two eroding natural islands (Hart and Miller) which were greatly increased in size, greatly modified, and jointed. Since Hart-Miller is all but full, another Chesapeake Bay natural island, Poplar Island, is being designed to be the next CDF to hold material from the Bay navigation channels. The island originally was approximately 1,500 acres in size, and was an upland island with perched wetlands. Poplar has eroded so severely that it is now less than 5 acres in size, and the water-bird nesting colonies that were originally so abundant there are nesting in remnants of dead trees standing in the water. An emergency protection effort using barges that were floated into a semicircle and sunk to form a breakwater is currently in place.

The Poplar Island CDF 1,100-acre design calls for massive armored dikes to provide dredged material storage, to restore lost upland and perched wetland habitat, to create additional intertidal wetland habitat, and to provide further protection and water quality improvements in the area between the island and the Eastern Shore mainland (Landin et al. 1995). One technique being tested for a dike core in this highly disturbed area is using geotextile tubes. Tubes have been placed in a small demonstration area and stacked to determine if it will be possible to use them as a dike foundation and core. Since this just occurred, no monitoring results are currently available. This will be a new application of tubes, and if successful, will carry tube use and tube risk to new levels. The alternatives to tube use are varied, but they all cost considerably more than the tube alternative. One problem they have encountered is that much of the foundation material is fine grained, and sand will have to be found to fill the tubes. Since height, density, and stability inside the dike are critical parameters, fine-grained material is not suitable. Any contingency for failed tubes at Poplar CDF will be to replace or bury the tubes within the dike with borrow or barged-in material.

Delaware Bay Estuaries and Shorelines. The New Jersey and Delaware shorelines of Delaware Bay have been eroding severely for many years, and both States historically have lost many miles of salt marsh from erosion. As part of the Delaware River Channel Deepening Project, the Corps intends to use approximately 40 MCY beneficially, including 10 MCY in the lower Bay. Plans and designs call for wetland and habitat restoration, beach nourishment, endangered species habitat, and general shoreline protection using the primarily sandy dredged material. Due to the need to hold down costs and soft foundations that will not support riprap, the District wants to use geotextile tubes to provide breakwaters to protect the restored wetlands. Designs at the New Jersey wetland site call for a single layer of tubes, backfilled with sand dredged material to an intertidal elevation in some areas, and mounded in others for horseshoe crab spawning. Designs at the Delaware wetland site call for stacking tubes to provide temporary protection to some fine-grained sediment that will have to be placed there. Semiconfined wetlands will be the resulting habitats.

In this area of 7-ft tides and almost daily wind-driven wave surges, tube precedents are nonexistent except for European examples, where they have had some problems with rolling and stability in high tides and wave energies. The risk of long-term failure is great, and it is assumed in the design that the breakwaters will have a finite life. The goal for the Corps is "short-term" success, so that the material is stabilized as it is moved from the channel, and so that the sites will provide habitat restoration and improvements for as long as possible. While State agencies and the U.S. Fish and Wildlife Service would like long-term wetland and shoreline stability, they had to recognize that this would be extremely difficult unless permanent breakwaters were built of stone, and even these might fail. Currently, the Corps plans no contingencies at the two wetland sites for long-term failure. They are planning short-term fixes if they occur during or immediately after construction.

Where Does This All Lead? Environmental restoration attempts in the coastal zone have a checkered success rate, with well-designed and implemented sites generally very successful, and less well-motivated mitigation sites having a high failure rate, especially over the long term. There are many complicating factors, such as the influence of urbanization, sediment trapping in rivers and reservoirs that starve some estuaries of needed nourishment, and nonpoint and point source pollution. Although some people consider sea level rises a great complicating factor, it is such a long-range problem that it really has little influence over environmental restoration projects. The greater danger by far is subsidence, the opposite of sea level rise.

The Corps has been forced to spend a lot of money keeping dredged material out of circulation, and therefore out of natural resource and beneficial use projects, when the need was for the material to remain in managed circulation and nourish the habitats that need it (marshes, mudflats, shorelines, and beaches). Dr. Landin noted that Corps scientists have been working diligently to educate and promote understanding of the ecological consequences of decisions regarding dredging over 20 years ago.

The question is asked, what does this have to do with tubes? Tubes are one of the lower cost technological tools that allow both engineers and biologists to address and accomplish beneficial uses of dredged material and habitat restoration. Any time the Corps recommends and encourages such a tool, it assumes certain technical and sociopolitical responsibilities and risks, should a tube project fail. Can the Corps, its contractors, and its partners afford to fail? The need for solid multidisciplinary design and implementation is rather critical, as is the need for identifying contingency alternatives until tube projects are considered so routine that no one will question their purpose and utilization.

To emphasize how important this can be, Dr. Landin noted cases in which engineers are trying to build tube projects without the collaboration of biologists, and vice versa, without success. The engineering plan may seem sound, but it will not meet ecological functions and goals. Likewise, biologists may have goals that are technologically infeasible, and they need to understand problems associated with the engineering of habitats and beneficial-use projects. Tube projects also need to have some level of predictability. However, generic designs that tend to come from trying to provide predictable results will often go awry because each project will have differences in all of the factors previously identified by all of the workshop's presenters. A conclusion is that multidisciplinary (often intraorganization) teams who identify and address alternatives, identify and address ecological and structural function requirements, and who bring as much expertise and experience to the project as possible will reduce risks and reduce the need for contingencies.

Discussion following Dr. Landin's presentation focused on some of the technical problems encountered (e.g., soft foundations), unique habitats and tubes (e.g., mangrove restoration), and on some of the nontechnical issues that tend to get in the way of accomplishing technical goals and objectives. She noted that it is important to establish relationships and partnerships with all entities concerned over a project. Partners tend to be those people and agencies who are going to cost- and work-share the project, landowners, agencies with regulatory responsibilities, and other pertinent groups. The new terminology out of Washington is "stakeholders," in which Federal agencies now have to work with virtually anyone who may have some interest at any level in the project, however minor and motive driven. Dr. Landin noted that stakeholders are not generally traditional cost-sharing partners

One of the best means the Corps and other organizations has in dealing with this new expansion of involvement is the development of long-term planning and management strategies for watersheds or dredging reaches. These often have 50-year lives and are signed off on initially. They also include periodic revisits to evaluate progress and success, and they can be used as a vehicle to head off unwarranted changes and challenges by poorly informed newcomers to the project. Dr. Landin noted that it is important to be aware of these kinds of solutions and alternatives in environmental projects, including those that use geotextile tubes.

Final Discussions and Summary

Mr. Jack Davis and Dr. Mike Palermo queried participants for final thoughts and ideas regarding geotextile tube applications, using the following questions.

What tube information needs to be written and published? There are at least 11 broad categories of information regarding geotextile tubes that should be collected and made available to tube users.

(a) **Applications and the Functions To Be Met.** This workshop has identified a number of tube applications, including wetland restoration, protection, and creation, island stabilization, dike and berm stabilization, safe containment of contaminated and/or fine-grained sediments, aquatic and other habitat development, and beach protection. Besides the technology associated with using tubes to engineer such applications, there are a number of ecological functions that may be required, depending upon goals and objectives of the project and the type of project it is. These functions may include wildlife diversity and abundance, finfish and shellfish diversity and abundance, sediment management, erosion control, flood-flow alteration, groundwater recharge and discharge, storm surge protection, native vegetation recovery and sustainability, and water quality improvement. In addition, there are several human values that possibly become associated with tube projects, including historic and cultural resources, aesthetic appearances, education and training, and sociopolitical institutional issues. The interrelationship among these functions and values, as well as the ramifications associated with engineering and tube technology, needs to be evaluated and that information made available as rapidly as possible to prevent mistakes and failures.

(b) **Advantages and Disadvantages of Tube Use.** Workshop participants identified and discussed a number of advantages and disadvantages of tubes. Advantages tended to be associated with lower costs, successful beneficial uses of dredged material, ability to use tubes on soft foundations, ability to tie a series to tubes together for shore or beach protection, flexibility in working in difficult access areas (including using and removing water-filled tubes), and usefulness in containing and isolating contaminated material. Identified disadvantages covered a broad range of possibilities, including (a) lack of permanency, (b) tendency when used incorrectly to roll, move, or undercut, (c) vulnerable to vandalism, (d) only useful as longer term breakwaters when filled with sand material, (e) fine-grained materials use primarily limited to contaminants storage and isolation, (f) only appropriate in low to moderate wave energy conditions, and (g) hard to successfully stack, especially in high tidal ranges.

(c) **Tube Material Characteristics.** Several different types of fabrics have been used for tubes and large bags. In years past, large nylon bags filled with either sand or grout were used with much success and longevity in Galveston Bay, partial success in North Carolina, and near complete failure in the Great Lakes. Sand-filled Longard tubes made of polyethyl (?) were used in Chesapeake Bay, Florida, and the Great Lakes, with partial success. At the present time, custom-designed and sized tubes are made of either (a) nonwoven materials, (b) polyester, or (c) polypropylene. Each fabric and material has advantages and disadvantages; however, nylon and polyethyl is now seldom used. The newer materials are predicted to be very long lasting (20- to 30-year life), but have not been installed for long enough time periods nor sufficiently field tested to allow movement beyond the experimental stage. Most managers and researchers who are using tubes are doing so with the intention of gaining information (both good and bad) as the projects progress and especially by postproject monitoring of both engineering and environmental parameters.

(d) **Planning and Conceptual Designs and Placements.** There was much discussion throughout the workshop on this topic area. In general, most people treated this topic like problems identified here were nontechnical constraints. However, careful planning and design often identify problems that may not have been readily apparent. There are a number of conceptual designs for tubes, especially stacked or tiered tubes, that have been tested under limited circumstances. Conceptual designs and placements are areas still requiring work.

(e) **Development of Appropriate Goals and Objectives.** It was noted throughout the workshop that firm goals were not set for all projects, or if they were, they could change in the field. Everyone agreed that appropriate goals and objectives were needed for tube projects, but it was noted that flexibility needed to remain in those goals so that in-field changes could take place if necessary due to wind and wave conditions or other factors.

(f) **Collect Baseline Technical and Engineering Data.** This has often been a shortcoming in tube projects and was one reason that so much in-field compensation and changes were necessary. It is critical to have a good understanding of energy forces, hydrology, foundations stability and slope, sediment quantity, quality, and texture before tubes are designed and placed at a site.

(g) **Construction and Implementation Specifications.** Standards have not been set for geotextile tube applications such as wetlands or shoreline protection; therefore, specifications for contracts and for in-house work are still being developed. It is not currently possible to plug a set of standard specifications for tubes into a contract and get a predictably successful project. This field is so new that the Corps has no list of potential contractors available competent to construct tube breakwaters or structures. These areas require additional effort.

(h) **Construction Techniques.** Everyone participating in the workshop had used different techniques under different circumstances in constructing their tube projects, and most had built few enough tube projects to know what would routinely work. There is much left to be learned about construction techniques, including critical timetables, working in various weather conditions, when to use lined versus unlined tubes, working on slopes, and numerous other factors.

(i) **Monitoring and Long-Term Maintenance of Tubes.** Tube integrity was identified as a frequent problem, whether it was sediment seeping slowly out of tubes, vandals, or sediment escaping through open filling ports. These problems do not generally surface right away, and engineering monitoring is necessary to maintain integrity. This would include repair of tubes as soon as damage is discovered. So far, this has been a limited effort, and should be expanded greatly in every project.

(j) **Container Shape and Size.** Various sizes (lengths and circumferences) have been tried, and most participants agreed that the larger tubes used (2000 $\times$ 45) are too unwieldy and hard to fill. Size, configuration, stacking, and shape should be modeled to give recommendations based on wave energies, tidal ranges, and other factors. This topic is one that could be considered for inclusion in the ADDAMS model for dredging decision making.

(k) **Past Experiences and Lessons Learned.** Geotextile tube technology is still in the experimental stage in most cases, although there have been a number of tube projects that have worked as planned. Questions arise with regard to individual sites differences, strength and stability, moderate to high wave energies, and other factors, with little hard data to answer questions. The primary way to learn is to continue to build tube projects and to monitor their results carefully to add to experience and expertise.

In addition to the above discussion, some of the unanswered questions brought out by workshop participants included the following:

a. Applications with regard to biological and structural function.

b. Calculation of stresses on tubes in a routine manner.

c. Effects on marine life.

d. Importance of strength, survival ability, longevity, and stability.

e. Mesh size related to grain size (permeability).

f. Availability of tubes from various manufacturers.

g. Developing computer models for baseline tube conditions.

h. The use of grout or other firm substances instead of sand in tubes.

i. Problems with seams (seam strength relative to fabric strength, location of seams, how to sew seams in the field).

j. Water quality.

k. Biota use of tubes (good or bad?).

l. Ice flow stability and strength.

What applications are most appropriate for tubes? Applications already constructed include use as groins, shore protection, beach protection, island construction, cleanup of Superfund sites, disposal of contaminants, oyster and sea grass bed restoration, dike regrading, permanent or temporary structures for wetland restoration or creation, and dike protection. In addition to these, tubes could effectively be used in any circumstance that calls for a small dike, berm, or levee. After tube stacking technology is more ensured, applications could increase greatly.

Which characteristics of dredged material are important to successful tube deployment and habitat development? Sand dredged material is the preferred material in almost every possible situation using tubes. However, in the case of disposing of contaminants, fine-grained materials have been and can be placed in tubes for the purposes of tying up the sediments for many years and placing them out of harm's way. The ability to pack densely in a tube and raise its height to the maximum, while at the same time not allowing sediment to seep through fabrics or to retain large quantities of water, seems to be critical.

What are the hydrodynamic factors involved? A number of hydrodynamic factors were identified: overturning; sliding; overtopping; relation to pressure, sediment type, and height; design monograms; buoyancy; wave impacts; and rolling. Hydrodynamics change with shape, slope, and water depth.

What are the geotechnical factors involved? Most of the geotechnical discussion focused on ways to more accurately predict final tube height in filling, and it was noted that there may be a trade-off in height-to-width ratio. Height might make a tube roll. Some of the other questions involved the following:

a. How to get the fill to consolidate?

b. How to achieve height with various types of fill?

c. How does underwater tube fill differ from on-land or intertidal fill?

d. Properties of foundations.

e. How is the scour blanket and anchor tube constructed and used?

f. Is tube size only a function of getting the scour blanket to sink and behave?

g. How long should segments be?

h. How to determine stable tube configurations that may be stacked, overlapping, abutting, or other concepts?

How do we deal with risks and uncertainties associated with a "new" technology? There are many risks and uncertainties associated with new technology. We must provide better technical and nontechnical guidance for tube applications. Better ways to optimize construction are needed, because this is a major cost factor. Better information is needed on tube deployment and filling techniques. It is also very important to document what has been done (lessons learned, what works and does not work). Many of the innovative ideas that have been successful were developed by Corps contractors who were left to figure out how to put tubes in place and meet their obligations. Partnerships among contractors, agencies, and sponsors need to be worked out so that all have an equal playing field, and so that contract specifications are written to allow contractor flexibility where warranted.

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Appendix A: Field Trips

Port of Houston Authority Wetland Demonstration Project, Atkinson Island, Houston Ship Channel

Mr. Richard F. Gorini, Environmental Manager, Port of Houston Authority; Mr. Grady Bryant, Principal, Gahagan and Bryant, Inc.; Ms. Tracey Koenig, Staff Scientist, Turner Collie and Braden, Inc.; and other staffers who have worked to successfully build a large dredged material wetland as a demonstration site for the Houston Ship Channel Deepening and Widening Project conducted an extremely interesting and informative tour of their site. This wetland was built within a cove on an existing dredged material island and is protected by a permanent earthen core breakwater that has two sets of weirs providing intertidal connection. The breakwater at the site had several ongoing tests being conducted on stabilizers: (a) geotextile tubes placed along the water's edge against the breakwater, (b) geogrids that were filled with small stones, (c) erosion control fabric that had plant sprigs planted within it, and (d) a control that was left unprotected.

Likewise, the marsh itself had several experiments taking place. The U.S. Department of Agriculture (USDA) Natural Resources Conservation Service and Americorps had planted the site in experimental plots of seeds, single-stemmed sprigs, and multiple sprigs, as well as leaving a control (unplanted) area. These plantings were with a new improved variety of native smooth cordgrass (*Spartina alterniflora*) that was disease resistant. In addition, near the weirs, extant smooth cordgrass propagules from nearby areas began to grow in the marsh. A comparison is planned between the original and the improved stands of cordgrass. A number of other excellent marsh plant species have also colonized the area in and among the cordgrass plantings. A monitoring effort is scheduled. Tests of planting techniques were also being made (mechanical versus hand versus a combination of the two).

The partners of this project, the Port, the Corps, the U.S. Fish and Wildlife Service, National Marine Fisheries Service, State of Texas, and USDA Natural Resources Conservation Service, have worked very hard to not only build a successful site, but to develop and cultivate a true atmosphere of interagency and multidisciplinary cooperation and sharing. Without this effort, the demonstration project would never have happened. Much of the success goes to the project chairman who would not take "no" for an answer, Dick Gorini.

Corps Tube Projects in the Gulf Intracoastal Waterway

The Galveston District conducted a day-long field trip to three of its geotextile tube sites along the Gulf Intracoastal Waterway. Trip hosts were Messrs. Neil McLellan and Tim Few. Participants traveled to the sites by boat and van and met initially at the U.S. Fish and Wildlife Service Aransas National Wildlife Refuge office, where the first sites were located. All of these sites were discussed in detail during the presentations portion of the workshop.

Ayers Island and False Live Oak Island. These two sites were located on Aransas National Wildlife Refuge. One was constructed using tubes, while the other was constructed using riprap. Both had dredged material placed behind them and were planted with *Spartina alterniflora* to hasten salt marsh development. The tubes were performing exactly as planned, designed, and constructed. Since one tube failed here, participants looked at it, but found little evidence of problems. The failed tube had been overlain with a good tube that was holding. Scour at the ends of the tube rows was blocked by placement of concrete bags. The tubes had colonized with thick coats of algae and were being used by shorebirds and other marine organisms. Wind-driven waves were overtopping the tubes; but that primary force of the waves was broken, and there was little impact on the protected marsh.

A noticeable difference between the two areas was that waves overtopped the tubes, but were not overtopping the riprap. The riprap was maintaining itself at a higher elevation than the tubes. Only time will tell as to how important that is to marsh success. Both marshes were growing well; however, at the riprapped site, wild hog digging and grubbing were impacting the new growth. No efforts have been made to compare the two sites, and almost no effort has been made to monitor either site. The District is observing engineering progression; however, no one is monitoring the wetlands or their colonization by fish and wildlife.

Victoria Barge Canal. The Victoria Barge Canal project enclosed maintenance dredged material with tubes on each side (the channel side and the Bay side). The tubes were holding very well and also had colonized with thick mats of algae. However, they were not as high as intended. That did not seem to matter, as the marsh (unplanted) was colonizing with a variety of brackish marsh species. The tubes were anchored into existing island areas and formed a plug that filled eroded spots. At this site, young trees and marsh grasses were growing through the geotextile fabrics. Also, most of the material here was fine grained rather than sandy material.

Port O'Connor. The final project was built by the Corps for the City of Port O'Connor to separate a dredged material sand beach from an existing sea grass area. As noted in presentations, vandals had cut this tube in a number of places, and it was experiencing erosion from the tube. The tube had a thick mat of algae and numerous crustaceans on it. It also was being used by shorebirds and gulls for perches. In spite of the cuts, the tube was functioning as planned, and sand was accumulating on the opposite side of the tube from that anticipated (accumulating on the sea grass side, not the beach side). In hindsight, there was no need for this tube, but it has provided some experience and lessons on tube technology and utilization.

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The U.S. Army Corps of Engineers has used increasingly in recent years geotextile tubes filled with sand for the retention and erosion protection of dredged material in low wave energy, low-tidal range regimes. Because little design and construction guidance for such application is available, a workshop was conducted to document the state-of-knowledge of geotextile tube design and deployment. The workshop focused on existing capabilities to design geotextile tube structures and lessons learned from field deployments. The presentations and discussions are summarized, conclusions are discussed, and suggestions for future research are provided.

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